VOL. XV*.

RUDIMENTARY TREATISE

ON

CIVIL ENGINEERING.

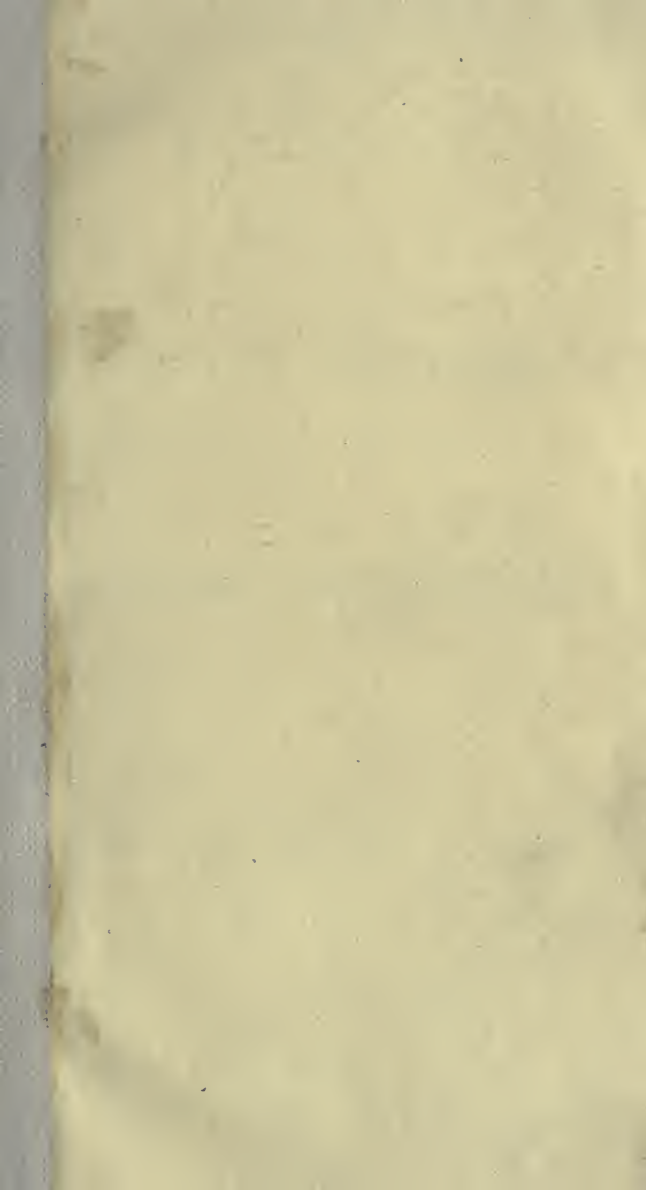*Hydraulic Engineering*

VOL. III. PART II

With Illustrations.

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JOHN WEALE.

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THE

RUDIMENTS

OF

HYDRAULIC ENGINEERING.
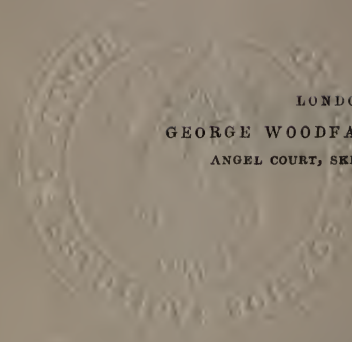
BY G. R. BURNELL,

CIVIL ENGINEER.

VOL. III. PART II

London:

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M.DCCC.LII.

PREFACE.

THE lengthened delay which has taken place in the publication of the third volume has been occasioned by the small portion of time which my professional engagements have allowed me to devote to literary pursuits, and which time has been obliged to be divided between this and several other works. In order that no further delay should occur, I have relinquished the task of completing that portion of the present volume relating to Hydraulic Engineering to Mr. Burnell.

<div align="right">HENRY LAW.</div>

6, Duke Street, Adelphi.
    19th May, 1852.

In accepting the task of completing the portion of the deservedly popular Treatise on Civil Engineering which Mr. Law's engagements have forced him to decline, I would fain request the public to extend to me the indulgence usually accorded to those who find themselves called upon to endeavour to fill in an outline sketched by another hand. In this particular instance it has been my aim to confine my observations within the range of the synopsis inserted by Mr. Law at the commencement of the first volume. Insensibly they have far exceeded the limits he had proposed, and this branch of the work has attained a development perhaps greater than it merits in proportion to the remainder. But the very nature of the phenomena connected with Hydraulic Engineering is so complex that these appeared absolutely to require to be examined in detail, in order to arrive at a correct general view of the subject; and, lengthy as this portion of the Treatise may appear, it is to be feared that much has still been

omitted—many objects of study and investigation rather hinted at than explained.

To facilitate the researches of those who may be disposed to pursue the investigation of this most interesting branch of the profession of Civil Engineering, a list of the most celebrated authors who have treated of its details has been annexed. The list is far from being complete, but it contains the names of all who have fallen under my own personal observation. I have drawn from many of these sources largely, and have endeavoured to quote my authorities when there seemed to be any originality in the observations. Yet there are doubtlessly many instances in which I may not have acknowledged the full extent of my obligations. The fact is, that, in the domain of the exact sciences, so many discoveries have become public property, so to speak, that they seem to form the staple of our knowledge, and to be used without reference to their authors. By a species of tacit consent, when a law has once been admitted, it seems that it is the right of the next comer to use it with the same freedom as the discoverer; and so many such laws are being every day added to our stock, that in the end a kind of confusion prevails as to the parties to whom we are really indebted. It has, however, been my object in all cases to render honour to whom it was due.

Personally, I regret that the limits of the Treatise did not allow a more lengthened investigation of the subject of the supply of water to towns, and the application of the sewage. These are subjects so prominently before the public at present, and so many questionable doctrines have been promulgated at the expense of the nation, with respect to them, that it behoves every engineer, as far as lies in his power, to counteract the mischief it has been endeavoured to effect, and to recall the attention of the public to the real merits of the case. To do so completely would require another field than a Rudimentary Treatise; nevertheless, even in it, there is both room and reason to call attention to some of the theories

propounded by incompetent persons. The misfortune in England is, that if an investigation into any subject be undertaken, it is usually made in the manner so pleasantly described by Beaumarchais, and " if a mathematician be required we take a dancing master;" or literally, if an inquiry be made, and any subsequent measures adopted, in subjects connected with engineering, the parties it has lately been the custom to consult, are the omniscient barristers-at-law, not those who have devoted their whole lives to the study of the questions it may be desirable to elucidate. And it is also to be observed, that the two professions of Engineer and Barrister-at-Law are precisely the only two learned professions which can be taken up without examination or diploma. The remedy to so great an evil is hard to discover, unless it lie in the freedom of the press. Unfortunately, the action of the latter is slow, and much mischief is done before the public can be fairly roused to the consequences of following the instructions of its blind guides. Nevertheless, " Magna est veritas et prevalebit !"

<div align="right">GEORGE R. BURNELL.</div>

14, Lincoln's Inn Fields,
    July 15th, 1852.

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SUPPLY OF WATER TO TOWNS.

THE questions which affect the choice of the source and
means of supply of water to towns are those connected with
the qualities of the water itself, in the first instance; and, in
the second, the relative conditions of the difference of level,
and the distance between the source resorted to and the place
in which the distribution is to be effected. All waters, as is
well known, are not equally adapted to domestic use; and
those which are so adapted are rarely found in the precise
localities where they are to be used; so that in almost all
cases it is necessary either to bring the supply from a
distance, or to raise them above their natural level.

Notwithstanding all that has been said in the controversy
respecting hard and soft waters, there is still very great
uncertainty as to the precise qualities required in those to be
distributed in towns; and the public cannot be too frequently
advised to hesitate before it adopts implicitly the opinions of
men who, though neither engineers nor physiologists, have
lately assumed to dictate upon the subject. Unquestionably
excessive hardness is an objection to a source of supply; but

some of the chemical combinations which give rise to this
characteristic, if they only act within certain limits, are
stated by the most eminent authorities to render the slightly
hard waters more adapted for human consumption than any
others.   Soft waters, again, are unquestionably more pleasant
and agreeable for domestic use than hard waters; but their
very softness may be owing to the presence of ingredients
able to affect, slowly but surely, the physical organization of
those constantly using them.   Habit modifies the action of
particular waters upon the human frame; and it is notorious
that those accustomed to any one (whether soft, as flowing
from the primary rocks, or hard, as affected by the carbonates
or the sulphates of lime) are always seriously affected when
they begin to use what would be universally considered a
better water.   Dogmatical assertions are as dangerous in this
case as in all others; and, at least until competent authorities
shall have decided what really constitutes the perfection of a
water supply, questions of economical expediency must ulti-
mately decide the course to be adopted in the majority of
cases.

In the present state of uncertainty attached to this subject
it may suffice to adopt the conclusions laid down by Thénard,
and to pronounce those waters to be fit for domestic use
which are fresh, limpid, and free from smell—able to boil
vegetables without affecting their colours, and to dissolve
soap without leaving curds.   They should be very slightly
affected by the nitrate of baryta, which will indicate the
presence of the sulphates in combination; by the nitrate of
silver, indicating the presence of the chloride of sodium; by
the oxalate of ammonia, indicating the presence of the salts
of lime; by the ferro-prussiate of potash, indicating the
presence of salts of iron; or by the other chemical tests
usually employed.   The residuum, after evaporation, should
be very small.   A certain proportion of carbonic acid gas is
considered to improve the digestive properties of water for
drinking purposes; and nearly all physiologists, from the

time of Hippocrates to the present day, assert that, in small quantities, the chloride of sodium and the bicarbonate of lime are also essential.

The temperature of water is of nearly equal hygienic importance with its chemical nature, and it should be as constant as possible; that is to say, compared with the atmosphere, it should be warm in winter, and cold in summer. Aeration is an important condition, for the oxygen thus communicated forms, in fact, an essential element of the salubrity of water. Vegetable and animal matters, either in suspension or solution, must be removed: not only because they are disagreeable in themselves, but also because they absorb the oxygen in suspension in the water, and cause the latter rapidly to putrify. The presence of this class of impurities may be detected by chlorine solutions, or by an infusion of gallic acid.

After all, the most efficient method of ascertaining the real qualities of a water supply is, to observe the effects it produces upon the organized life resorting to it, especially upon the human beings using it. Organized life is, in fact, a far more delicate test than any chemical agents can ever be; and it is eventually affected by impurities too minute to be ascertained by the grosser appliances of science. Such waters, therefore, as are habitually used by vigorous, powerful, and healthy populations, can never be pronounced to be unfit for domestic consumption, whether they be hard or soft, or whether they contain salts of lime, or salts of soda, or potash.

Rain-water, collected in the open country, or at sea, a short time after the commencement of a shower (for the first drops that fall carry down the impurities in suspension in the lower strata of the atmosphere), is the purest that can be obtained. In storms it sometimes contains nitric acid; on the sea-coast it is often brackish; at all times it is aerated, but flat, and insipid to the taste, and apt to cause colics, probably from the absence of carbonic acid gas. For industrial operations it is generally considered to be the most advantageous.

Snow water is without air, and usually deposits a small quantity of dust on being melted; ice water is bright and pure, but difficult of digestion. The loathsome disease, the *goître*, is usually attributed to the use of snow water; but the healthy state of the crews of Captain Parry's ships during their long arctic voyages, when they had no other resource than the dissolved ice and snow, would appear to show that, if proper precautions be taken, they may be resorted to without inconvenience. Indeed, as several of the sources of soft water from the earlier secondary formations produce glandular swellings analogous to the goître, it would be reasonable to infer that the latter must be owing to the matters contained in the snow, rather than to any qualities inherent in the waters derived from it.

Spring waters depend, for their qualities, upon the nature of the strata through which they pass. They are fed by the rain-fall soaking partially into the ground at a higher eleva-tion, and finding its way to the surface at such points as offer less resistance to its escape than it meets in any other direc-tion. As pure water, such as falls from the clouds, has a remarkable affinity for many of the earthy bases, and for the gases with which the latter combine, it must be evident that the springs will become impregnated with both, in proportion to the time they are exposed to their influence. Rivers, again, are formed by the confluence of springs and small streams fed by the drainage from the watershed; conse-quently, near their sources their waters must participate in the respective properties of the latter. In their course, however, they may acquire a degree of purity far greater than exists in the several affluents; especially if they run over a rocky or a sandy bed, and do not receive any organized matters draining from the lands they traverse. Much of the gas taken up by the springs in their underground course may be given off in this manner, and even many substances in a state of chemical combination may become separated. It is not, therefore, always true that the nearer the source the

purer is the supply; but, on the contrary, so much do waters often gain by exposure to the atmosphere, that many physiologists are of opinion that river waters are preferable to those obtained from springs.

The extent to which waters are improved by exposure to the atmosphere must naturally depend upon the nature of the impurities they may contain. Thus the carbonic, and sometimes the sulphuric acid gases, are parted with easily, and the earthy carbonates deposed; but the sulphates of lime and the chlorides of calcium and magnesium are retained much longer. Often the distinguishing elements of two streams may be traced for a considerable distance below the point of confluence; and, again, it may frequently happen that the impurities contained in either of them may facilitate the deposition of those contained in the other. The greatest practical inconvenience attending the use of waters taken directly from their source appears, however, to lie in this— that they are, under such circumstances, certain to depose their earthy salts in the conduits employed in their distribution. Such waters as contain the bicarbonate of lime, or the hydrous oxide of iron, are especially exposed to this objection.

Collection of Water from Surface of Ground.

The small streams collected from the watershed of a country must be affected by the considerations above described; that is to say, their qualities must depend upon the strata over which they flow, upon the organic matter carried into them, and their exposure to the atmosphere. It must be borne in mind, in all these discussions, that it is now generally admitted that, of the total rain-fall supplying the fresh water of a large tract of country, one-third flows off in the shape of rivers above ground, one-third is employed by the vegetation or again evaporated, whilst the last third penetrates the ground to supply deep-seated springs and wells; or, at least, that

these proportions hold for the majority of cases. It is the former quantity, therefore, that must be calculated upon, in all cases where it is proposed to obtain a supply from the watershed of any particular district; at least, unless it be possible also to secure any deep-seated springs.

Now, it must be evident, that, as the streams from the watershed of a district are supplied by the rain flowing immediately off the land, they must vary considerably in volume; and that in winter, or the rainy season, they will be full, whilst in summer they will be comparatively dry. The variations in volume will depend upon the greater or less equality of distribution of the rain-fall, upon the configuration of the country with respect to the outlines of hill and dale, and upon the capacity of the superficial strata to absorb and retain water during wet weather, and to part with it during droughts—in fact, upon their capacity to store water, and thereby equalize the flow. All these combined causes have been observed to produce very great irregularities; and it becomes necessary, when a constant equable supply is to be obtained from a given watershed, to construct reservoirs so as to store the excess of one period against the penury of another. The dimensions of the reservoirs must depend upon the distribution of the rain-fall, and it may be laid down as a rule, that they should be calculated more with reference to the maximum demand and the minimum supply, than to the average of either. A capacity of storage equal to about six months' consumption, in addition to the quantity which is likely to be evaporated, appears to be the least which should be admitted when it is proposed to supply any agglomerated population in this manner.

Waters thus stored are much exposed to deteriorate in quality. They develop with singular rapidity both animal and vegetable life, and the decomposition of the latter, when in a state of decay, communicates elements of future combinations of the most repulsive and noxious description.

Such reservoirs must be filled necessarily with stagnant waters; and these, if exposed to the atmosphere, must also be exposed to the variations of temperature of the latter.

The following rules should be observed, wherever local circumstances will allow, in the construction of reservoirs: that the capacity be obtained by increasing the depth, rather than the surface; that the sides be as nearly as possible vertical; and that they be covered, so as to protect them from atmospheric influences, amongst which may, perhaps, be included the sun's light, for it appears to be the most efficient cause in promoting vegetation. The expense attending the execution of these works is so enormous that there can be but very few cases in which they ought to be undertaken; and, indeed, in all cases where covered reservoirs are required, very careful and elaborate comparative estimates of the cost of all other sources of supply should be made.

It may be interesting to state that the cost of some large canal reservoirs has been about 450*l.* per million gallons of water stored. No town reservoirs appear to have been constructed at a less cost than about 600*l.* per million gallons; whilst the Croydon Reservoir, the only covered one yet constructed, cost rather more than 4000*l.* per million gallons, including the price of the land.

A well-executed system of catch-water, or of thorough drainage, would unquestionably increase, to a remarkable extent, the quantity of water derivable from a given area, but it will in nowise diminish the necessity for constructing the storage reservoirs, but rather, on the contrary, augment it; for, necessarily, the storage capacity of the ground itself is diminished, in the direct proportion of the perfection of the drainage. The formation of a system of thorough drainage is also a very expensive operation; and, when combined with the necessity for reservoirs, it must lead to so great an outlay, that it may safely be asserted that the system of collecting water from what it has lately become the fashion to call

"gathering grounds" should never be resorted to, if any other can reasonably be adopted. However, it has been calculated that if the situation of the proposed gathering grounds offer steep declivities with narrow gorges, it is possible to obtain from it two-thirds of the total rain-fall—although hitherto no instance can be cited where such favourable results have been long obtained, for the efficiency of the drains becomes rapidly deteriorated.

Use of Springs.

Where springs, fed by the infiltration of rain-waters falling upon a large area, occur in considerable abundance, and of the requisite quality, they may be considered to offer the most desirable sources of supply in all highly-cultivated districts, because it is hardly possible to exclude drainage waters from flowing into superficial watercourses. The precautions, before alluded to, as being necessary to secure the deposition of the matters in solution which would otherwise choke the pipes, must be taken. It is also important to ascertain what is called the yield of the springs under all the varying meteorological conditions of the locality. Gaugings of any watercourse during two or three months are of very little use in cases of this kind, because the springs being supplied by the rain-fall it follows that they must vary with the variations of the weather. Unless observations, then, be extended over the whole cycle of the climate (in England, of about seventeen years' duration), the indications to be derived from gaugings over short periods are very likely to mislead in calculations with respect either to the average or the minimum flow. The period of the year when gaugings are taken will also materially affect the correctness of the observations, because not only does the rain-fall vary with it, but also the springs are observed to be affected at an interval of from one to five months, according to the nature of the strata. As the greatest quantity of rain falls during

the later autumnal and the winter months, it appears that, if it be necessary to confine the observations within very short periods, the most advisable course is to make them during the months of September and October; for, generally speaking, the springs are at the lowest about that period Even then, the indications are very likely to be fallacious, and, unless observations be carried over the whole cycle, the yield may occasionally fall far short of that calculated upon.

In the second edition of the "Treatise upon Well-Boring and Sinking" in this Series, the questions connected with the Theory of Springs are treated more in detail than can be done on the present occasion. It may, then, suffice to observe here, that springs are generally divided into two classes, land-springs and deep-seated springs, according to the structure of the district from which they derive their supply.

Land-springs are those fed by the waters falling upon loose permeable materials lying upon a retentive substratum, through the former of which they descend until the latter opposes their downward progress. As such waters are not under hydrostatic pressure, they cannot rise above the ground; but, on the contrary, they rush into any artificial depression in the upholding substratum. The majority of common wells are supplied in this manner, and are to be met with in almost every position. The waters they yield are, however, likely to become stagnant, deficient in aeration, and to take up any soluble salts existing in the ground or in the masonry lining their sides.

Land-springs are often met with in towns, as, for instance, in London, Manchester, Paris, Southampton, &c.; but from recent observations, it appears that, in all such cases, they are very much exposed to take up the nitrates produced by the decomposition of vegetable and animal matters in the ground, and are, in fact, often particularly unwholesome.

Deep-seated springs are those deriving their supply from the exposed surface of a stratum situated at a high level, then passing under an impermeable stratum, and lying upon

another impermeable basin-shaped deposit. The water, under such conditions, follows the levels of the lowest portions of the permeable stratum, according to precisely the same hydrodynamical laws it would obey if flowing upon the surface. Should an opening be made through the overlying impermeable stratum, the water will rise to a height corresponding with the hydrostatical pressure upon it, excepting insomuch as it may be affected by the friction it meets with in its traject, or by the existence of any natural overflow. These overflows frequently are to be found at the points where the permeable stratum passes under the impermeable one; and are to be accounted for by the fact, that, the lower basin being gorged with water, the fresh supplies, filtering through from the more elevated districts, force their way out at the edge of the basin. Or, again, the overflows may be explained by the existence of a fault, or dislocation, of the strata, which interrupts the subterranean flow of the water, by bringing, perhaps, an impermeable stratum in contact with the edge of the one holding water.

The chalk formation exhibits some very remarkable illustrations of these observations, and, in many places, it throws off springs of extraordinary beauty and volume. Thus, near Amwell and Chadwell, in close proximity to the outcrop of the basement beds of the London clay, are found the celebrated springs which gave rise to the New River, now, unfortunately, almost entirely supplied by the Lea. At Bury St. Edmund's a very powerful spring, called the Mermaid's Pits, is brought to the surface on the side of a transverse valley, which appears to be attributable to a fault. Near Southampton, the Otterbourne Spring rises at the point of junction of the outcrop of the basement beds of the London clay with the chalk. Near Weymouth, the springs of Sutton Poyntz and of Upway are thrown up at the points where the great fault of that peninsula affects respectively the chalk and the oolitic formations. In the districts where the carboniferous series are found, the effects of the faults are

even more strongly marked; and, in the portion of the West Riding of Yorkshire near and round Halifax, an immense number of springs are given off at the points where the regular stratification of the beds is interfered with by the series of faults and upheavals, which have fissured and contorted the whole surface of the country.

Deep-seated springs such as these are naturally more constant in their volume than land-springs, in precisely the direct proportion in which their supplying strata are more powerful. It is, however, impossible to predicate what may be the quantity to be obtained from them, unless by a careful investigation of the area of the exposed surface, and of the conditions of level of the latter, as well as those of the ordinary water-line, and the other natural overflows of the district. Even these will not dispense with the necessity for gaugings, but they may prevent the absurd outlay which has sometimes been incurred in the endeavour to pump dry springs of this nature—a piece of folly actually performed of late upon one of the most copious of those above cited.

Artesian Wells are, in fact, nothing more than excavations through the overlying impermeable stratum supposed above to exist upon a permeable water-bearing stratum, underlain again by an impermeable one. They form, as it were, artificial outlets for the waters contained in the lower parts of the basin, and the water-line in them will depend upon the hydrostatical pressure existing upon the same lower parts. This, as said before, will be influenced by the level of any natural overflow which may exist around the edge of the retaining stratum. The conditions of success in an artesian well depend upon the perfection of the basin formed by the water-bearing stratum, so far as the mere retention of the water is concerned, and upon the level of the streams flowing from the water-bearing stratum, so far as the height of the water-line is concerned.

The quantity of water to be obtained from an artesian well must, therefore, be regulated by the area of outcrop of the

water-bearing stratum; and that it is far from being un-limited is proved by what has occurred at London, Tours, and Milan. There is also a consideration which ought to be borne in mind before commencing any work of this kind, or, indeed, before it is attempted to appropriate any deep-seated spring to the uses of a town population; and this considera-tion is, that the legislation upon the subject of underground watercourses is in utter confusion at the present day. Neither in England, nor in any other country, are there any fixed principles regulating the decision of the law courts upon this subject; and, in the only three cases hitherto submitted to our courts, it so happens that each one has been decided upon grounds reversing the principles of the former decision. Unfortunately, lawyers are rarely geologists or engineers; nor do engineers, when called upon to advise the lawyers, appear to have shown much knowledge of geology, so that the fortunate discoverer of a valuable supply of water, as the law stands, may see it intercepted by a neighbour who has quietly observed the results of his experiment; or he may find his only remedy to lie in an action, whose result must, above all others, be exposed to the "glorious uncer-tainty of the law."

The various physical conditions necessary to insure the success of artesian borings, also introduce great uncertainty in their results. Thus the well of Grenelle yielded a copious supply at the depth of 1802 feet; in the valley of the Loire several successful works have been executed, with an average depth of 500 feet; whilst one other, in the same district, of 628 feet in depth, and a second, 454 feet deep, were abandoned, after the usual retaining basin of the district had been traversed, on account of the absence of supply. At Calais, an artesian boring, 1150 feet deep, was made unsuc-cessfully through the chalk and subcretaceous formations into the carboniferous series. At Chichester, at a depth of 1054 feet from the surface, no water was obtained from the upper green sand; and at Southampton the boring was discontinued

at a depth of 1317 feet from the surface, being still in the chalk.

It would thus appear, after all, that the only infallible source for a water supply is to be found in rivers, although unquestionably there are often serious objections to their use. Thus it almost always happens that they receive the drainage waters from cultivated lands and inhabited districts ; and the daily-spreading habit of making their beds serve as the outfall for sewage tends seriously to increase this evil. When rivers are resorted to, it becomes, therefore, necessary to place the supply-conduits at points beyond the reach of such sources of impurity, and, in almost all cases, to form settling reservoirs and filter beds, so as to remove the extraneous matters present in their waters.

It must, however, always be understood, that, in cases where any one course of proceeding has been recommended in preference to another (as, in this instance, it is stated that rivers offer the only infallible source), it is not intended to recommend its adoption to the exclusion of all others. There can be no rule in engineering, of this kind at least, from which it may not be advisable occasionally to deviate ; and it is emphatically in this profession, perhaps more than in any other, that the economical adaptation of means to the end must ever decide ultimately the course to be adopted.

The quantity to be distributed in a town is usually assumed to be about at the rate of 20 gallons per head per day, calculated upon the whole population. This quantity would include all that is generally required for municipal and trade purposes, unless when the latter are of the character of cotton printing, dyeing, or scouring cloths, &c. In London, the supply is rather beyond that quoted above ; in Paris, also, it is above 20 gallons ; but, where accurate observations have been made, it appears that really the average daily consumption for every human being is about 7 or 8 gallons, and that in summer they require from 20 to 30 per cent. more than in winter. Municipal requirements vary, of course,

according to the habits of the country, but they rarely exceed 10 per cent of the total consumption; and ordinary trade purposes, together with the inevitable waste, make up the remaining quantity short of the 20 gallons per individual per day usually assumed to be required.

The parties considered to come under the designation of large consumers, and as such giving rise to an extraordinary demand for water, are manufacturers, tanners, fell-mongers, hair-washers, glue-makers, curriers, dyers, hatters, brewers, distillers, inns, bath-houses, and steam-engines. If many such exist, it will be necessary to provide especially for them; which, of course, would place the rate of payment upon a different footing from that to be applied to the public in general.

Mode of ascertaining the Amount of any Source.

The probable supply from any given source will be ascertained by direct experiment in the case of wells, whose hydrographical conditions may be unknown; or by a calculation of the areas and water-bearing capacity of the strata feeding them, should these be ascertained. It is important, however, in the former case, to make the trials at the season of the year when the underground flow is at the lowest, and to avoid any exaggeration in the estimate in the latter case.

Springs may be gauged either by causing them to flow into vessels of known capacity and observing the time required to fill these, or by causing them to flow through pipes of known diameters and observing the velocity; or, finally, by damming them up so as to destroy any initial velocity, and then allowing them to fall over a weir. The indications thus obtained must be affected, nevertheless, by what has been previously stated with respect to the causes of irregularity in their volume, so far as the rain-fall, and the structure of the beds from which they flow, are concerned. This subject, as well as that connected with ascertaining the volume of rivers and watercourses, has already been

treated in the introductory chapter of Hydraulics. The reader is also referred to the observations upon the different sources of supply, for indications as to the means for ascertaining the qualities of the water: it may, however, be as well to observe, that inquiries of this description involve questions of delicate chemical analysis, and that, therefore, they should be always referred to the most eminent philosophical chemists who can be found.

Mode of Distribution.

When the source of supply shall have been determined upon, it becomes necessary to consider the system of distribution to be adopted. Formerly, in almost all English towns, this was effected by what is called the intermittent system, in which the water was supplied from the mains during a greater or less number of days in the week, and stored in cisterns for domestic use in the intervals. This system still prevails in London and in many other towns. Of late years, and principally by the influence and authority justly attached to the name of its most zealous advocate, Mr. Hawksley, beyond all dispute the ablest engineer practising the peculiar branch of the profession connected with the distribution of water, a system known by the name of "the constant, and high pressure," has been introduced. It consists in so arranging the supply, that not only the mains, but also the house services, are always charged, day and night, and the pressure is usually such as to insure the delivery of water at the highest level in a town at which it can possibly be required.

Abstractedly considered, there can be no doubt but that, in every point of view, the constant delivery must be the best. Any person who would take the trouble to look at, for it is not necessary to examine, the various receptacles (butts, tanks, or cisterns) used to contain water, in the poorer parts of towns especially, cannot fail to be disgusted with the foul contagion to which the water must be exposed. In

the houses of the rich, some precautions are taken to remove
cisterns from the soot and filth of our town atmosphere, to
place them beyond the immediate effects of the variations of
temperature.   But it is far otherwise with the houses of
many of the middle, and of all the poorer classes; and in
them, the recipients for the waters required for domestic use
are almost always placed in positions where they cannot fail
to become corrupt, and to imbibe principles highly injurious
to the hygienic condition of the unfortunate beings con-
demned to use them.

In an economical point of view, the assertion of the advo-
cates of the constant supply, that their system is preferable,
seems also born out by facts, although Mr. Wicksteed used,
formerly at least, to deny that it was cheaper.   Evidently the
cost of the cisterns themselves must be saved; and, as the
draught upon the mains takes place during a greater portion
of the day, and the momentary consumption, so to speak,
must be less, the dimensions of the pipes may be diminished.
It may be questioned, however, whether eventually there be
any economy on the latter score; because it will be necessary
to increase the strength of the pipes, and consequently their
cost, in order to obviate the effects of the hydraulic jars pro-
duced by opening and closing the several house-services.
From this cause, and from the necessity it superinduces of
placing the house-services upon a series of subsidiary mains,
called riders, it is possible that the cost of the pipes may be
equal in both cases; but the economy resulting from the sup-
pression of the private cisterns would not the less exist.

The suppression of private cisterns, it is true, renders it
necessary either to form regulating reservoirs, or, if the water
be pumped directly into the mains, to use machines able to
supply the maximum demand.   Such a general reservoir
must, however, be far less expensive than several separate
works of a similar character, even if of the same aggregate
capacity.   It also appears that it is far more advantageous to
construct such reservoirs, than to establish machines of the

power required in the case of their omission, and to place these reservoirs at such heights as may maintain a constant pressure upon the pipes.

From observations made by Mr. Martin at Wolverhampton, it appears that the most copious consumption of water, in towns supplied by the constant system, takes place between the hours of 8 and 12 in the day, and again between 2 and 4 in the afternoon; the hours at which it attains its maximum limits are between 11 and 12, and 3 and 4, respectively. Between 8 and 12 about one-fourth of the total supply is usually consumed, and between 6 in the evening to 6 in the morning not more than one-fifth of the total supply is drawn off. From these indications it would appear that, theoretically, a service reservoir able to contain a minimum quantity of about one-fourth of the total supply, would suffice to regulate it in such a manner, that the machines should be able to maintain it by a constant equable effort divided over the ordinary working hours. In adopting some such arrangement, another advantage would be obtained; viz., that if the demand should increase, it would be possible to meet it, simply by making the engines work longer. If, on the contrary, it be found or thought advisable to pump into the mains, without the intervention of any regulating reservoir, the engines must be calculated so as to supply at all times the maximum draught upon the mains, which, according to the same authority, will be about one-twelfth of the total quantity between the hours of 11 and 12, and of 2 and 3. They would be forced to work all night; and, at the same original cost, would not be capable of extension.

The site to be chosen for the reservoirs must be, so far as economy of construction only is concerned, as near as possible to the source of supply, if the latter be situated at a low level; or to the commencement of the distribution, if the waters be led from a great distance. It is advisable, also, wherever it can conveniently be effected, that all such reservoirs be placed out of reach of the impurities of the at-

mosphere of all large centres of population; and that they
be protected from dust and soot, as well as great changes of
temperature.   These considerations are often of so great im-
portance, that they may cause it to be preferable to augment
the engine-power, and construct the reservoir at a lower
level, even if they do not lead to the abandonment of the
latter altogether.

In addition to the remarks already made, with respect to
the construction of reservoirs, in this and the preceding
chapters, it is necessary to state, that whenever such works
are to be executed for a town supply, they must be formed of
such materials as are not likely to affect the qualities of the
waters they are intended to receive.   In all cases of this
description, to a certain extent the waters must be stagnant;
and they are then likely to absorb any soluble salts contained
either in the earth or in the masonry of the wall.   It
appears, therefore, to be very doubtful whether water in-
tended for town distribution should be stored in reservoirs
which are puddle-lined or pitched with calcareous stones. Sili-
cious sandstones, hard-burnt bricks, or the argillo-calcareous
stones, bedded, where necessary, in powerfully hydraulic limes,
or in cements, or iron, protected from the immediate che-
mical action of the water, are unquestionably the most advis-
able materials to be used in forming the faces immediately in
contact with the water.   The positions of the inlet and outlet
pipes should be arranged in such a manner as to insure a
constant flow through the body of water in the reservoir;
and precautions should be taken to keep back any impurities
which might be introduced, by either forming depositing-wells
under the inlet-pipes, or by placing gratings or filters over
the heads of the outlets.

The other accessories to reservoirs intended to hold waters
for town distribution are simply—1, the valve-pit, placed at a
small distance from the outlet through which both the pipes
are made to pass if possible: it is formed for the purpose of
working and examining the respective valves by means of

which the water is admitted to or excluded from the reservoir or the pipes, as the case may be; 2, the overflow-pipe, waste-weir, or other provision for regulating the height of the water; 3, the scouring or cleansing-pits, with a discharge-pipe placed at such a point as to allow the whole of the water to be drawn off if requisite; and, 4, means of access to the bottom of the reservoir. It is desirable, and practically it is almost always so arranged, that the outlet pipe be so placed, that a certain depth of water should always be retained, excepting when the cleansing pipe is opened. The object proposed by this arrangement is, to allow a more effectual deposition of the mechanical impurities of the water.

When the source of supply finally chosen is at a lower level than the points from which the distribution is to be effected, or than the highest point to which the water is to be delivered, it becomes necessary to employ some mechanical agent to raise it. For all town purposes, the choice of the particular agent is limited either to steam or water power, according to the circumstances of the town under consideration; and in both cases the motive power must be applied to pumps, because they alone, of the various descriptions of intermediate machinery, can force the water to the height and the distance it is generally required to overcome.

Evidently it must be preferable to adopt water-power, wherever it exists to a sufficient extent, because it costs nothing beyond the first outlay for the machinery and the ordinary repairs; whilst steam-power, on the other hand, requires a constant outlay for coals, and also a much more continuous and expensive attendance. But it rarely happens that such a power is to be met with in the immediate neighbourhood of large towns; and in the majority of cases it is found that the streams giving the motive power are so exposed to interruptions in their flow, from ice, floods, or droughts, that they are seldom used in cases of this description, in which regularity of action is a matter of such serious importance. The determining motives in the selection must,

then, depend upon the cost of the maintenance of steam-
power, and the interruptions the water-power may be exposed to
(supposing it to exist). If these interruptions should not be
of any serious duration, they may be obviated by increasing
the size of the reservoirs; but, of course, it would be neces-
sary to make this consideration enter into the calculation
insomuch as it may affect the final cost. The problem to be
resolved in all similar cases is, to raise within a given time
the greatest quantity of water which may be required, at the
least possible expense, not only for the moment, but eventu-
ally.

In estimating the power to be provided, it is necessary to
take into account the weight to be raised; the height, or dead-
lift to be overcome; and the various causes of retardation of
flow, arising either from the friction upon the sides of the
pipes, or from any changes in their direction, whether in a
horizontal or vertical direction. These last-named causes of di-
minished power will be discussed hereafter; but the diminution
may be, generally speaking, covered, by allowing for an extra
dead lift of 12 feet per mile of the conducting pipes between the
engine and the reservoir, unless any very extraordinary verti-
cal bends exist. For instance, let it be supposed that 1000
gallons per minute are required to be raised to a net
height of 120 feet above the lowest clacks of the pumps, or
the water-line in the pump-well, and to be discharged at a
distance of $2\frac{1}{2}$ miles. Then, as a gallon weighs 10 lbs. avoir-
dupois, in round numbers the calculation would become,
$10,000 \times (120 + 30) = 1,500,000$, moment of resistance. Now
as a horse-power nominally is considered to be equal to
33,000 lbs. raised 1 foot high per minute, theoretically the
power should be $1,500,000 \div 33,000 = 45.46$-horse power.
But a steam-engine rarely works up to the nominal power,
and a water-wheel falls short, even to a greater extent; so
that, in cases where the former is to be used, it becomes
necessary to affect the theoretical result by the coefficient
0.85; and where the latter, by the coefficient 0.75, for the

most perfect description of water-wheel, and in the best working condition. It would be necessary, then, to provide a steam-engine of about 53·5-horse power, and a water-wheel of about 60·7-horse power, to perform the duty above supposed.

The towns of Philadelphia and Richmond, in the United States, and of Toulouse, in France, are supplied by water-wheels, all undershot. Of these, the wheels at the Fairmount Water-works, Philadelphia, are the most remarkable, on account of the volume of water they are designed to lift. This is not less than about 10,000,000 gallons per day, with a dead-lift of 92 feet, through cast-iron pipes 16 inches diameter. The engine house is built for eight wheels and pumps; the former being 16 feet diameter, 15 feet on the face, and with a fall of 7½ feet, on the average, and making thirteen revolutions per minute. At Richmond there were two wheels 18 feet diameter, 10 feet on the face, with a 10 feet fall, working two pumps, and raising 800,000 gallons per day into reservoirs situated at a height of 160 feet above the low-water. At Toulouse, the wheels are 14 feet 5 inches diameter, 5 feet on the face, with a fall of about 7 feet 6 inches; they are two in number, and raise about 896,000 gallons per day, to a height of 67 feet above the water in the well.

The description of water-wheel to be employed must, of course, depend upon the conditions of the flow of water in the river; it may be undershot, overshot, or breast, according to the height of the fall, or the volume flowing through the sluices. Of the undershot wheels, those constructed upon Poncelet's system, with curved floats, and working in a close concentric channel, are the most economical, and yield the greatest effective power. With a fall of 5 feet, or under, they produce a dynamical action equal to 0·75 of the theoretical power employed; with greater falls, this coefficient descends to 0·60; whilst undershot-wheels, with straight floats, rarely produce a dynamical effort equal to the latter, and they are exposed to the serious inconvenience of being

rendered unserviceable with a much smaller amount of back-
water than the Poncelet wheels.

Overshot wheels produce a dynamical effect sometimes as
much as 0·80 of the power actually employed; but, under
the ordinary conditions, and with a velocity of the periphery
of between 3 feet 6 inches and 7 feet per second, the dyna-
mical effect is only equal to 0·75 or 0·70 of the power. They
require that the supply of water should be constant, and that
the water flow away directly it leaves the wheel. These con-
ditions are sometimes obtained with difficulty, and under such
circumstances the breast-wheel is resorted to, because it can
work under greater variations in the supply, and with a
greater depth of back-water in times of flood. If breast-
wheels be constructed with the improvements introduced by
Mr. Wm. Fairbairn, the dynamical effect may safely be cal-
culated at 0·75 of the power exerted.

Turbines have also occasionally been applied for the purpose
of raising water, and they possess the remarkable advantages
of being applicable to any height of fall, of occupying small
space, and producing useful effects with very wide range in
the velocity. They yield a dynamical effect varying from
0·70 to 0·75 of the power, and may be employed in many
cases where no other description of wheel could succeed.

In most of our own large towns, steam-power is resorted to
for the reasons before cited, or because the water-power is
already appropriated. It appears from the practical results
hitherto attained, that when the power required exceeds 20 to
25 horses, the description of engine known as the Cornish
engine is the most advantageous. Below that limit, there is
more economy in the first cost and subsequent working of
more direct-acting engines, or even of small horizontal
engines with fly-wheels, communicating motion to shafts bear-
ing the pump-rods. In the case of the Cornish engines, or
rather in cases where large quantities of water are required
to be raised to great heights, the most favourable condi-
tions of movement are, to begin by raising the load rapidly,

and, after the first motion is perfectly determined, to diminish
the effort employed progressively, so that it may be destroyed
when the piston arrives at the end of the stroke. This is
effected by introducing steam, at great pressure, upon the
piston, through very large orifices, which is then allowed to
expand directly the inertia of the column of water has been
overcome, and it has assumed an ascensional movement
requiring for its maintenance a very small effort. In the
Cornish mines themselves, the initial pressure of the steam
is about from $2\frac{1}{2}$ to 3 atmospheres; the expansion begins
between $\frac{1}{8}$ and $\frac{1}{4}$ of the stroke of the piston; and at the end
of the stroke, the pressure is not more than from $\frac{1}{5}$ to $\frac{3}{10}$ of
an atmosphere. In small pumps, on the contrary, it is
necessary that the action should be uniform; and, on this
account, it is advisable to divide the action in such a manner
as to work three pumps, by means of cranks, forming with
one another angles of 120° upon the same shaft.

Should the only available source of supply be of a quality
to require filtration, it will be found advisable to perform
that operation at the very latest possible period before the
distribution takes place. However perfectly filtration be per-
formed, whether by chemical or merely by mechanical agents,
if the water be stored for any length of time afterwards, it
will infallibly develop or take up impurities. The course
adopted by some of the London companies—filtering the
water, and then raising it into reservoirs, where it is exposed
during several days to the action of the atmosphere—is
radically incorrect. In such and in all similar cases, the
water should be allowed to settle at the lower level, and the
filtration should take place after it leaves the upper reser-
voirs. Precautions, however, must be taken to insure that
all impurities likely to choke the pumping-mains be re-
moved before the water enters them.

Wherever filters are used, it is customary to construct
before them settling reservoirs, in which the waters may
deposit the grosser impurities they may contain; and it ap-

pears advisable that these should be of sufficient capacity to
allow the water to settle during at least three days.   From
thence it must be led upon the filter, without velocity or cur-
rent, able to act upon the materials of which this may be
composed.   The filters themselves may be either chemical or
mechanical; that is to say, they may either alter the qualities
of the water, or they may merely act by removing impurities
in suspension.   To effect the former is necessarily a costly
and difficult operation, and, indeed, so much so, that it may
fairly be considered unattainable with the whole quantity
required for a town supply.   And if the water be immediately
taken from a good mechanical filter, with as great rapidity as
this can yield it, the quality will, in almost every case, satisfy,
not only the public demand, but also the real exigencies of
the case.

Of the various descriptions of mechanical filters in use,
the most important are those formed upon the principles
adopted at Nottingham and Toulouse; upon the principles
adopted by Mr. Thom at Paisley; upon those of the Chelsea
Water-works; or finally, by the application of filtering-slabs,
either natural or artificial.

The Nottingham and Toulouse filters consist of a series of
tunnels, formed in the sand of the beds of the respective
rivers from which the supply is taken.   Wherever the mate-
rials of the bed are of a nature to allow this course to be
adopted, it appears to be the most economical; but it is liable
to the serious objection, that if the tunnels become choked
in any way, their repairs are very difficult; and, as the
efficiency of any filter depends upon the head of water over
it, this class must evidently yield the least in the summer
months, when the demand, on the contrary, is the greatest.
It very frequently happens, also, that the construction of the
tunnels gives vent to springs of very different qualities to
those derived from the rivers; and it must always be observed,
that the geological conditions which render the construction
of such filtering tunnels possible do not occur in all cases,

but that, as a general rule, the beds of rivers, in large valleys at least, are formed of a partially impermeable silt, or clay.

The Paisley filters are stated to be chemical as well as mechanical in their action. They are formed by excavating the ground to a depth of from 6 to 8 feet, and surrounding them with impermeable retaining walls and bottom. The floor is divided into drains by means of fire-bricks placed on edge, and covered with flat tiles, perforated with numerous small holes, and supporting six distinct layers of gravel, increasing in fineness as they rise, which again are covered with very clean, sharp, fine sand, 2 feet thick, of which the upper 6 inches are mixed with animal charcoal. Theoretically, this would be the most perfect system of filtration; but it is to be feared that the cost would be very great in the majority of cases.

The Chelsea filters consist chiefly of four beds of carefully cleaned gravel of variable thicknesses, but with an aggregate depth of 3 feet, and increasing in fineness as they ascend, which are eventually covered with a thickness of 3 feet of fine washed sand. The objection to this system of filtration, which also applies to both those already described, is that they require a large area, and therefore give rise to expensive earthworks; especially as the depths to which they must be carried in order to obtain a head of water above, and the tunnels and pure water well below the filtering materials, must be considerable.

It is on account of the area and depth necessary for the other descriptions of filters, that the use of slabs becomes frequently the most economical, inasmuch as they dispense with the necessity for so great a thickness of the filtering medium. The artificial filtering slabs made by Ransome and Co. possess an advantage also in this, that the degree of porosity may be regulated at will, and therefore the area may be regulated precisely according to the degree of purification required. Again, in this instance, as in so many others, the

precise course to be adopted must depend upon local considerations of economy or expediency.

In addition to what has been already said upon the subject of the flow of water in pipes, it is important to observe that the resistances to which it is exposed in practice are of a fourfold character; depending upon—1, the friction on the sides of the pipes; 2, the retardation caused by the bends; 3, that arising from the changes of direction from the mains to the submains or branches; and 4, the gurgitation which occurs at every junction.

The friction on the sides of the pipes depends upon their diameters and lengths, and the head upon the respective orifices; and, practically, this again is modified by a coefficient varying with the velocity of the water. Taking it into account, the quantity flowing through a pipe of uniform diameter, receiving its water from a reservoir at a high level, and discharging it constantly into another reservoir at a lower point, without any change of direction in the pipes, may be ascertained by the formula $Q = c \sqrt{\dfrac{H + \zeta - H'}{\lambda} D^3}$, in which Q = the quantity; ζ = the difference of level between the extreme orifices; λ = the length of the pipe; H = the head at the upper, and H' = the head at the lower, orifices respectively; D = the diameter; and c = a coefficient to be derived from the following table :—

Velocity per second	2 in.	4 in.	8 in.	12 in.	15 in.	20 in.	78 in.
$c =$	15·06	17·22	18·83	19·50	19·84	20·07	20·79

and for any length beyond $c = 21·043$.

This formula, however, requires that the velocity should be previously known; should this not be the case, it may be ascertained as follows :—Call the sine of the inclination I, and make $K = \dfrac{H + \zeta - H'}{\lambda}$, in which the notation previously

observed will be followed; then we should have, according to De Prony's formula, as given by Playfair,—

$$V = -\cdot1541131 + \sqrt{\cdot023751 + 32806\cdot6 \times \frac{D\,K}{4}}.$$

In practice, however, the conditions to be dealt with are not so simple as those above supposed, and it becomes necessary to adopt other methods of calculating the resistance, which may be explained as follows, nearly in the words of D'Aubuisson. When water flows from a pipe, the vertical height of the surface of the fluid in the reservoir above the discharging orifice is called the head, and is represented by H in these observations. The velocity due to this head is, however, diminished by the friction upon the sides of the pipe; so that the portion of the head acting upon the discharging orifice can only be represented by the height able to produce the velocity of the discharge. If this velocity be called v, the height producing it will be $\frac{v^2}{2g}$; and $H - \frac{v^2}{2g}$ will be the portion of the head destroyed in creating it, and this portion, expressed in numbers, is known as the "loss of head."

As this loss of head is caused by the action of the sides of the pipes, it will be proportional to their length and their contour. In proportion, however, as the section increases, the resistance from friction on the sides will diminish, because it will be distributed over a greater number of molecules, and consequently will affect each one as well as the whole mass to a smaller extent; it will be, in fact, in the inverse ratio of the dimension of the section. The retardation will then be proportional to the square of the velocity with an addition of a fraction of the simple velocity itself. It is to be observed that, in the course of these observations, the pipes are always supposed to be full; for if they were not, the flow of the water would be regulated simply by the laws affecting it in its course through open conduits.

Calling the length of the pipe L; S, the section; C, the contour; and a b, two constant coefficients; the expression of the resistance will be, $a \dfrac{C L}{S} (v^2 + b v)$, and we should have $H - \dfrac{v^2}{2 g} = a \dfrac{C L}{S} (v^2 + b v)$. It is then only necessary to ascertain the values of the coefficients a b in order to apply the formula to ordinary purposes. Almost every author who has written upon this subject has attributed to them different values, so that great uncertainty still is attached to the correct solution of the problem. But it appears that the formula and values given in Weisbach's " Mechanics" are sufficiently accurate in practice, and they have therefore been adopted in preparing the Table No. 3. Weisbach calls the loss of head h_1, and confining his attention simply to the length and diameter of the pipe, he makes

$$h_1 = \left(0 \cdot 01482 + \frac{0 \cdot 017963}{\sqrt{v}} \right) \frac{l}{d} \cdot \frac{v^2}{2 g} \text{ feet.}$$

It is true that Messrs. Provis and Peacock's experimental inquiries appear to indicate an important error even in this estimate of the values of the respective coefficients; but as the results obtained from their application are admitted to be always in excess, it would certainly be advisable to adhere to them in designing any works for the distribution of water through pipes; because any imperfection in the manner of laying, or a suddenly increased demand, might render necessary the supposed exaggeration of diameter they would lead to.

The table indicates the quantities discharged through pipes of the dimensions given, and the loss of head occasioned by its flow at the respective velocities in the margin; or, in other words, it shows the additional head required to maintain the supposed initial velocity calculated upon a foot lineal of the pipe. The discharge is calculated by the formula already quoted, $Q = S V$; and the initial velocity at the commencement of the pipe can at any time be ascertained by the formula

$v = \sqrt{2\,g\,\mathrm{H}}$; in which $g =$ the accelerating force of gravity $= 32\frac{1}{6}$ feet, and $\mathrm{H} =$ the head over the point of discharge from the reservoir into the pipe, leaving out of account the contraction of the fluid vein, which may at all times be compensated for by making the mouth of the pipe accord with the best form of conical ajutage.

The friction, and consequent loss of head, is considerably increased by the existence of any changes in the direction of the pipes, whether horizontally or vertically; and it is found to be in a certain definite proportion dependent upon the ratio of the width of the tube to the radius of curvature of its axis. Navier states that the loss may be represented by the formula

$$h_1 = \frac{v^2}{2\,g}\left(0{\cdot}0039\,\frac{1}{r} \; + \; 0{\cdot}0186\right)\frac{a}{r},$$

in which $r =$ the radius of the curvature, and $a =$ the development of the arc. According to him it would appear that h_1 is proportional to the square of the mean velocity, and to the length of the arc; it is a function of the radius, and independent of the diameter of the pipes; and that h_1 decreases in proportion as r increases.

It is usual to make r of the following dimensions when side mains branch off from a leading main:—

Diameter.	2 to 3 in.	3 to 4 in.	6 in.	8 in.	10 in. and upwards.
Radius...	1 ft. 6 in.	1 ft. 8 in.	2 ft. 6 in.	3 ft. 6 in.	5 feet.

It is also to be observed that in vertical bends the rate of delivery is also affected by the collection of air at the summit, and by the loss of any portion of the dynamical effort of the head required to overcome the resistance of the column of water to be lifted on the lower side of the bend. The former inconvenience is obviated by placing air vessels at the top of the upper limb; the latter, by accelerating the rate of flow before arriving at the bend. It is important, however, that, in all cases where pipes are laid with deviations from the

straight line, they be kept constantly full, so as to prevent as much as possible any accumulations of air.

The pipes from the pumping stations to the distributing reservoir (and, generally, all pipes required for a town distribution) should be laid about 4 feet below the surface, and carefully covered with earth and sand, or some non-conducting materials. The object of this precaution is, to protect them against the effects of frost, to maintain an equal temperature in the waters, and to place them beyond reach of injury from shock or jar by passing weights. In some portions of the distance between the two stations it may also be advisable to insert double lines of pipes, and to make occasional connections between the two, in order that, in case of repairs to either of them, the flow may be maintained through the other.

These remarks have necessarily been confined to the consideration of the cases in which water is raised from a lower level and pumped through pipes. If the source, however, be situated at a distance, and at a higher level than the commencement of the distribution, the course to be adopted must necessarily be modified. In such cases, if no very serious obstacles are to be met with, it is preferable that the water be led in a conduit rather than in a pipe; for evidently the friction in the latter is much greater, and the height of the point of arrival diminished in proportion. Such conduits should be covered in all situations where the quality of the water is likely to be affected, as in the neighbourhood of large towns, or during their passage through forests and underwood; or, again, in warm climates, where the temperature not only acts injuriously upon the quality, but also gives rise to an evaporation of a very serious character. But if the conduits be so covered, there must still be adopted precautions for insuring a perfect ventilation and occasional renewal of the air; and in the Roman aqueducts, wells also were formed at occasional intervals, to allow of the deposition of any matters in suspension.

An advantage of great importance attached to the use of conduits, rather than of pipes, for the conveyance of spring waters, lies in this, that any of the earthy salts in solution which they are likely to deposit in the course of time, are not so likely to produce injurious effects in open culverts as they are in close pipes. The separation takes place, in air, at an earlier period of the flow; and it must evidently be more easy to cleanse or repair such conduits than it can be to perform the same operation upon pipes buried in the ground. On the other hand, it must be admitted that the construction of a small conduit is always a more expensive operation than the employment of pipes would be to ensure the discharge of the same volume of water; so that, eventually, considerations of economy may outweigh those derived from the theoretical advantages above cited. As an illustration of the extent to which the deposition of the earthy salts may interfere with and contract the effective area of a watercourse, the accompanying sketch of the transverse section of the conduit upon the celebrated aqueduct of the Pont du Gard is added. The portion shaded of a darker colour, round the watercourse, represents the deposit of calcareous matter which has gradually accumulated by precipitation from the waters, although great pains had previously been taken to ensure their purity.
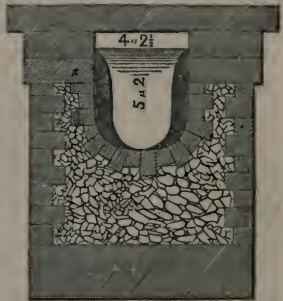
The most serious difficulties which are likely to be encountered in the construction of conduits, are those arising from the occurrence of hills or deep valleys in the line they ought to follow. The former, if of considerable elevation, will require to be traversed in tunnel; the latter may be passed either by aqueducts, or by syphons descending from a reservoir on one side, and remounting to a second at a lower level,

on the other; the conduit recommences from the second reservoir.

Amongst the relics of the Roman empire which have survived to our times may be found many very remarkable illustrations of both these manners of carrying across valleys the supplies of water intended for municipal distribution. As might naturally have been expected, however, in the defective state of the metallurgic arts amongst the ancients, the difficulties attached to the execution of large syphons led the Roman engineers to prefer the system of bridge aqueducts. Many of these are of such colossal dimensions, and such singular beauty, that it would be an injustice to mention them subsidiarily. The reader is therefore referred to the list of authors contained in the Appendix, should he desire to obtain further information upon this very interesting branch of the history of engineering. In modern times, the most remarkable works of this description are connected with the aqueducts constructed to convey to New York the Croton waters, or those executed for the supply of the town of Marseilles. Upon the former, in addition to a bridge aqueduct $1377\frac{1}{2}$ feet in length, with a maximum height of 150 feet above the foundations, there is a syphon aqueduct, with a depression of 102 feet in the deepest part, consisting actually of two cast-iron pipes 5 feet in diameter, with a provision for eventually placing two others of the same dimension. In the course of the latter, or the Marseilles Aqueduct, the total length of which is 98 miles, not less than $12\frac{7}{10}$ miles are in tunnel; and the valley of Roquefavour is traversed by a bridge 1312 feet long, with a maximum height of 282 feet.

The Turkish engineers introduced a system of interrupted syphons, if such an expression may be used, for the purpose of crossing long deep valleys, with the double object of saving the outlay necessary for the construction of masonry bridges, and of diminishing the chances of rupture in the earthenware pipes of which the syphons were formed. The name for this system is "souterazici;" and it consists of earthen pipes deriv-

ing their supply from an upper reservoir, descending a hill side, running along a valley, and then mounting perpendicularly into a second reservoir supported upon piers in masonry, at a rather lower level. From the second reservoir similar
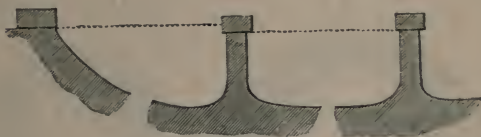
pipes were conducted down the opposite side of the pier along the valley, and successively into a third or a fourth reservoir at gradually decreasing elevations, and so on to the other side of the valley. Evidently this was a very rude method of meeting the immediate difficulties of the case, and the loss of head from the numerous bends must have been considerable; but there was considerable ingenuity in the idea, and perhaps it indicated a better acquaintance with the laws of hydraulics than we are accustomed to attribute to the nation amongst whom the system arose.

The dimensions and form to be given to the tunnels must necessarily be regulated, so far as the minimum is concerned, by the consideration that the workmen must be able to use the various tools, and to push to the extraction pits the materials disengaged during their operations. The nature of the rocks traversed will also affect the sectional area of the excavation; for if it be of a nature to render lining indispensable upon the sides and top, as well as for the water channel itself, the dimensions evidently must be increased. A miner can work with tolerable efficiency in a heading of the size represented in the margin; but it must be considered as the minimum in all cases, because the constrained position of the workmen prevents their employing the whole of their

useful power, and below this size they could hardly advance
themselves, without at all being able to work. It is also im-
portant that the workmen should be able at any time to visit
and repair every portion of the tunnel. For these reasons
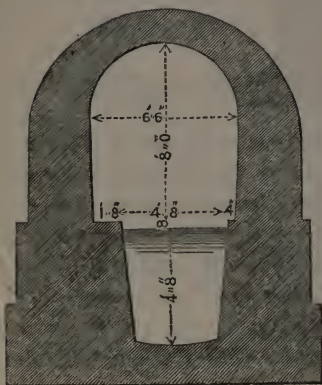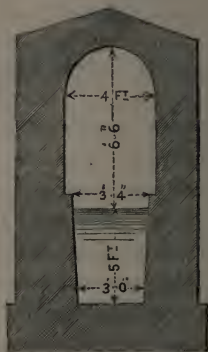
the conduit from which all the mains for the supply of Paris
draw the water is made of the dimensions indicated in
fig. No. 1 above. But it is also to be observed that this con-
duit, called the "Aqueduc de Ceinture," is about $1\frac{6}{10}$ mile
in length, and has only a fall of 4 inches throughout, so
that the flow of the water only takes place in consequence of
the difference of level caused by the withdrawal of the water
through the various pipes branching from it. The section is
therefore much larger than it would be otherwise; and perhaps
the desire to make it sufficient for the passage of a boat, hauled
by a man upon the species of towing path, may have led to
some exaggeration of its dimensions. Fig. No. 2 represents
the section of the branch "Aqueduc St. Laurent" joining the
"Aqueduc de Ceinture," and supplying one of the quarters of
Paris.

Whatever be the dimension given to the tunnel, or to the
watercourse of an aqueduct, directly it leaves the ground, to

be continued, as it were, in the open air, precautions must be taken to ensure the uniformity of the temperature. The practice of the ancient Romans, which was also followed in the erection of the Croton Aqueduct of New York, was to keep the top of the aqueduct, whenever possible, at a distance of 2 feet from the ground; and whenever it was necessary to carry it above that level, to cover the masonry with earth 2 feet 6 inches deep. It may, perhaps, be as well here to observe that, in spite of the criticisms of some late writers, the Croton Aqueduct is a very admirably executed work, and well worthy of study, if not always of imitation.

The formula which expresses the conditions of the flow of water in a pipe passing from one reservoir to another, ceases to be applicable when there is a series of side branches, or of sub-mains, deriving their supply from it. During the course of the distribution, a difference in the volume must necessarily arise from the fact that a portion of the water will be drawn off by these sub-mains; and in the latter portions of their course the supply mains must be diminished in dimension. But it may sometimes occur that the cost of new models for the smaller pipes may render it more economical to retain the original dimension; this question of detail will therefore require to enter into the comparative estimates of the various modes of effecting the supply. It is, however, necessary, before deciding the dimension of any main pipe, to take into account the probability of an eventual increase in the demand upon it.

Mr. Hawksley states that the method he adopts to ascertain the diameter to be given to the pipes upon the constant system, is to divide the length of the main in a street into portions of 200 yards each, and assign to every such portion the quantity it would be likely to require, supposing it to be discharged in four hours. He allows a loss of head of 4 feet for every 200

yards, and adopts the formula $\dfrac{1}{15} \sqrt[5]{\dfrac{q^2 l}{h}} = d$,

in which q = the number of gallons.

       l = the length of the main, in yards.

      h = the head, in feet.

      d = the diameter, in inches.

The course recommended by Claudel, in his " Formules à l'Usage de l'Ingénieur," is perhaps more accurate, although more tedious; it may be described as follows, nearly in his own words :—

Let it be proposed to supply a district by means of a pipe of uniform diameter throughout its length, and discharging the water by means of pipes constantly flowing. Then the diameter of the pipe should be sufficient to ensure the delivery of the water from each opening at a slight distance above the point of discharge itself. This diameter is assumed; and the
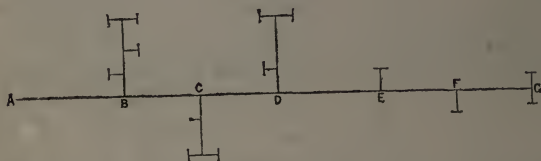
loss of head for the distance between A and B is calculated from the table; and, the loss being deducted from the initial head, will give that acting effectively at B, which must be sufficient to ensure the delivery of the water at the orifices upon the branch from B. The loss of head between B and C is ascertained in a similar manner, it being observed that the quantity discharged by the main will be diminished by the quantity withdrawn at B. As before, the head thus existing at C must be sufficient to ensure the delivery of the water required to supply the orifices placed upon that branch. Proceeding in this manner with the remaining branches, it will be seen whether the head existing at the last will be sufficient for its supply. If not, it will be necessary to try a larger diameter; if it be too great, a smaller diameter must be adopted.

Let it now be required to determine the diameter of a pipe receiving water from both ends, and supplying in its course certain orifices requiring definite quantities. In such a case it may happen that some of the orifices are supplied entirely from A; some entirely from B; whilst some, as D, for instance, may derive their supply partially from one, or from the other; or, it may be, from both.
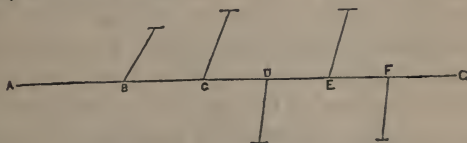
The diameter of the main in either of the parts D A, D G, must be such, that if D be supplied from both, the head at D and the consequent entry from both sides should be equal. It is necessary to proceed as in the last case, in order to ascertain that this is the case, and to assign some diameter to both A and G, and after deducting the losses of head occasioned by the several branches, B C E F, the remaining effective heads upon the respective portions of the main at D will be determined. Should they not be equal, one, or both, must be altered as the results obtained may indicate.

Should the supply main derive its waters from two pipes whose delivery is known, and should it be desired to deter-

mine the diameter of the pipe A B, so as to ensure a particular distribution upon its length, the course to be followed would be as follows. A certain diameter is assigned to A B, and as its discharge is known, and the difference of level between A and B is also supposed to be known, the effective head requisite to ensure the fulfilment of the required conditions is easily ascertained. If, then, the diameters of A and B be also supposed, as the volume to be supplied by them is known, it is easy to

calculate the loss of head upon each of them, which, being deducted from the initial heads at c and D, will give the net effectual head remaining at A. This head should be the same for both pipes, and equal to that required to secure the delivery already supposed to take place between A and B; and if the respective diameters should not be such as to ensure these conditions, they must be modified.

When the distribution takes place by means of a conduit of different diameters, it will be found that the system indicated in the first illustration will satisfy the required conditions, because the diameters of the pipes are constant between two successive openings, and the rate of delivery is also uniform between them. It is necessary, however, in calculating the loss of head, to allow for the difference in the diameter of the pipes.

In carrying out the working details of any town distribution of water, there are numerous precautions to be taken to ensure that the pipes should be protected from the jar of carriages and from the contamination of gas pipes *. A minimum depth of 4 feet from the surface will suffice for the former; and in order to guard against the latter, it is customary to place the water pipes at a lower level than those conveying the gas. Care is also required to be taken to avoid what are technically

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* It is usually considered that the temperature of the water is affected by the depth at which the pipes may be laid from the surface, on account of their being to a greater or less extent removed from atmospheric influences. But from the experiments made by M. Girard (see "Mémoire sur la Pose des Conduites d'Eau dans la Ville de Paris, 1831"), it appears that at whatever temperature the water may enter a pipe, if it flow continuously, it will leave it at precisely the same temperature. The experiments were very carefully made, but they require confirmation.

The same authority states, that the dilatation of cast-iron pipes was 0·00000300228 of a foot for every degree Fahrenheit, if free and in the open air; when the pipes were filled with water, and buried in the ground, the dilatation was considerably reduced. The pipe itself assumed a temperature which was a function of the difference of temperature between the surrounding media, and was nearer to that of the denser medium.

called "dead ends," or portions of the mains in which there exists no current, and in which necessarily the water must become stagnant. It is necessary, also, to make every sub-main, and, if possible, every house-service, independent of the other portions of the distribution, so that in case repairs are required of a nature to render it necessary to shut off the water, the privation may affect as few houses as possible. Sluices, or, as they are sometimes called, "hydrants," are placed close to the embranchments upon the mains; and it is advisable to place a small stop-cock at the junctions of the house-services.

Fire-plugs are placed in London at distances varying in the districts of each separate company, but it appears that, upon the average, there is a fire-plug to every ten houses. In large towns, also, it is advisable to place stand pipes at distances of about 500 yards, for the supply of water-carts. This branch of the public service is found to require a supply of about $1\frac{1}{4}$ pint per yard superficial for every time it is performed; and in our climate it appears that it is required for 135 days in the year, and in summer it will frequently be necessary to water the roads twice a day.

CHAPTER VI.

MARINE ENGINEERING.

THE phenomena which modify the action of large bodies of water upon works erected in them, or upon bodies floating upon them, and which it is therefore necessary to take into account where these are considered, may be grouped under the principal heads of the winds, waves, tides, and currents. The action and reaction of headlands, the effects of the outline of any particular sea-shore, the quantity of alluvial matter brought down by any rivers, the volume of the latter, and an infinite number of other modifying causes, also require attention. Within the limits of this treatise it will be impossible to enter into their examination in sufficient detail; but where-

ever it is possible to treat them incidentally, it has entered
into the plan of the work to sketch at least their general bear-
ings upon the practical operations of the engineer.

The Winds.

As is universally known, the wind blows over the earth
in every possible direction, with every imaginable variety
of intensity and duration, in the temperate zones; but
under the tropics it varies at definite intervals of time, as
well as prevails in constant directions.   In all countries,
however, notwithstanding the apparent irregularities, there
are *prevailing* winds easily to be ascertained; and, generally
speaking, those winds produce the most frequent tempests in
the localities where they blow.

The velocity and strength of the wind vary within a very
wide range, and it is usually considered that they may be
represented as in the following table, supposing the effect
produced to increase as the square of the velocity.

Name of wind.	Velocity per second.		Effort per yard square.
	ft.	in.	lbs.
Light breeze, hardly perceptible . . .	1	8	0·04989
Gentle breeze	3	4	0·19756
Light wind	6	8	0·79130
Rather strong wind, best for sailing . .	18	0	6·06996
Strong wind	33	0	20·06690
Very strong wind	66	0	80·26760
Tempest, or storm	70	0	101·62790
Great storm	90	0	146·34430
Hurricane	118	0	266·05670
Hurricane able to tear up trees, &c. . .	150	0	406·51180

The effort being supposed to be exercised in the direction
of the wind, and upon a surface, normal to it, of one yard
superficial area.

It has been also remarked, that in level countries the wind
blows downwards, forming an angle of about 18° 20′ with the
line of the horizon.

In consequence of this general direction and its velocity,
the wind, by its action upon the superficial layers of a large

body of water, can accelerate or retard their movement, according as its direction coincides or not with that in which those layers may be flowing; and it will develop upon them, as also upon still waters, a series of elevations or depressions. These variations of level are called *waves;* and they are the greater in proportion to the surface upon which they are produced, and the length of time the wind may have blown in the same direction and with the same force. The agitation will be increased if the wind should blow in a direction opposite to that of the current of the water; or if it should suddenly change its direction; or, lastly, if land winds meet waves generated at a considerable distance by other winds blowing in shore. This last meteorological condition recurs with sufficient frequency to have attracted the attention of sailors, and gives rise to one of the most dangerous forms of agitation to which the sea is exposed.

Some idea of the effect of the wind upon still waters may be formed from a fact mentioned by Franklin, viz., that in a pond 9 miles wide, with an average depth of 3 feet, a strong wind drove all the water from one side, which was laid bare, whilst on the other the water was increased 3 feet in depth, being 6 feet deep instead of 3 feet, as in the ordinary state.

Upon the sea-shore, and occasionally at great distances inland, the wind, by its action upon small incoherent materials, can frequently cause them to assume a progressive motion in its direction. Instances of this are to be found in the dunes of the Bay of Biscay, and the sands of the great deserts.

Waves *.

Waves, or undulations, are the alternate elevations and depressions in a vertical direction, which for all ordinary purposes may be assumed to be caused by the action of the wind alone, leaving out of account the very rare hurricane and earthquake waves which occur in some particular

* See Brémontier, Emy, Sganzin, Minard, &c.

districts. They are sometimes subdivided into waves and breakers; the former term being applied to the long undulations met with in deep water and in the open sea, or upon the sea-shore in still weather; whilst *breakers* are the violent waves caused by storms driving the water with violence upon reefs of rocks or upon precipitous shores. Colonel Emy, in addition to the above terms, uses also those of *long running waves*, or those possessing a movement of translation, and usually caused by the wind blowing from the sea inland; and of *chopping waves;* these are, in fact, only modifications of the running waves, from which they differ in this, that they do not appear to have any movement of translation.

Waves of different dimensions may often be observed advancing simultaneously in every direction, crossing one another at almost every angle, and presenting occasionally the appearance of great disorder. If, however, they be examined attentively, even during the most violent agitation, it may be perceived that each wave forms part of a system of undulations proceeding from some definite source of disturbance, and that this undulation could subsist in perfect independence of all the rest. The combination of such systems forms a multiple undulation; and it may be observed that a periodical increase of elevation takes place in the waves, which is attributable to such a combination of two systems of undulation; the one composed of the waves which are the most apparent, the other of those possessing greater extent, but less vertical height. Waves coming in from the open sea are, however, so much more powerful than the cross waves, that it is but rarely that we need consider them otherwise than as simple uncompounded waves.

Those portions of an undulation situated above a horizontal line passing over the normal plane of the water, are called its *crown*. The depressions separating the crowns of consecutive waves are called the *troughs*, and they are below the horizontal line above mentioned. The *length* of a wave is usually understood to mean the distance between the axes of

two consecutive troughs; the *height* is ascertained from the perpendicular distance between the bottom of the trough and the top of the crown.

The apparent motion of waves is one of translation; but if the real motion of the molecules of the surface be closely observed, it will be found that they merely oscillate in a vertical plane, without advancing in a horizontal direction. The movement of translation, then, only affects the form of the wave, but it in no wise modifies the position of the molecules; somewhat in a similar manner to the effect produced in a field of standing corn, where the waves caused by the wind appear to recede, but at the same time the stalks themselves are fixed. Or perhaps the apparent movement of waves may be more strikingly illustrated by the rotation of a screw upon its axis between two fixed points. The immobility of a floating body in the horizontal direction is, however, the most decidedly marked in the portions of the wave situated about the middle of the rising and falling sides.

Waves do not modify the natural current of the water upon which they are formed; so that a body floating upon the surface of a current will follow its direction, notwithstanding any superficial undulation. On the other hand, the current carries forward the waves existing upon it without in any way interfering with the mechanism of their movement of oscillation. Thus, calling the velocity of the waves that which they would possess in still water, their apparent velocity upon a current would be either the sum or the difference of their own velocity and that of the current, according as they move in the same or in opposite directions thereto. Colonel Emy, however, states that sometimes at the mouths of rivers the velocity of the waves rolling in from the open sea, is sensibly equal to that of the river current. Under these circumstances the waves form, as it were, fixed rolls or ridges, to which the current of the river is forced to adapt itself.

Waves produced by the wind, or by any other cause, may become superposed upon others, arising from similar causes, but at an earlier period. Like the undulations of sound or of light, they are known to cross one another in every direction without being affected in a manner able to destroy their respective velocities. But Brémontier observes that two systems of undulations may coincide at intervals of greater or less duration, and thus give rise to waves of greater elevation than those which either precede or follow them. The directions of liquid waves may, nevertheless, be inflected or reflected in precisely the same manner as those of light or of sound, and the waves so diverted from their original direction are known under the name of *reflected waves*.

Although it is well known that waves do not arrive upon the shore with either the same volume or the same force they possess in the open sea, they still retain a form and a velocity which, for all practical purposes, may be considered constant, so long as their cause subsists. But, again, although this may be considered to hold good for a comparatively short period of time, it must be borne in mind that the form and velocity are in fact very variable, depending upon the wind and the time it may have blown in one direction, even if we do not take into account the numerous local causes contributing to modify the action of the waves.

There are several theories to account for the formation of waves, which may be found in the works of Newton, Laplace, La Grange, Poisson, Biot, Brémontier, Emy, Virla, Young, Scott Russell, the "Philosophical Transactions," the "Transactions of the British Association," "Les Annales des Ponts et Chaussées," &c. For practical purposes it may, however, be sufficient to state, nearly in the words of M. Reibel, that the majority of engineers adhere to the hypothesis propounded by Newton, which accounts for the undulatory movement of water, by supposing that the vertical depression of the liquid molecules by any external agent, is transformed at the lower limit of the agitation of the sea into a

horizontal movement of communication, similar to that which occurs when the waters in one branch of a syphon are depressed. And it is to be observed that, when waves are produced by a cause acting instantaneously, as in the case of a heavy body falling, they are transmitted in concentric circular rings, firstly of feeble elevation, but subsequently increasing, and the oscillation in the various rings is isochronous. The equality of the surfaces of the hollow, and the increase of volume of the wave, and the incompressibility of water, appear to confirm this theory, which is, however, combated by several eminent engineers, amongst others by Colonel Emy, and after him by Mr. Scott Russell.

According to those authorities, the molecules of water in waves are affected by a series of orbicular movements, either simple or compound, whose intersections form the surfaces of the waves themselves. This theory explains in a very plausible manner many of the phenomena of waves; but it is far from being generally adopted, especially in the case in which it is applied to the explanation of simultaneous multiple undulations crossing one another.

It was long believed that the agitation of the sea did not descend to a depth exceeding from 16 feet to 17 feet 6 inches from the surface, and, so far as the waters of the Mediterranean only are concerned, this law is still believed to exist. Brémontier has, however, shown that in storms the agitation descends much below this depth, and he asserts that upon the banks of Newfoundland it even extends to the enormous depth of 530 feet from the surface. To the south of the Cape of Good Hope, breakers have been observed above rocks situated 660 feet below the still-water level; and recent observations in the Channel have shown that, although the agitation diminishes with the depth of the water, it descends far below the supposed limit of 17 feet. But it must be evident that the degree of violence of the agitation of the surface must considerably affect the depth to which its effects may extend.

The usual height of waves varies in different seas; thus, in the Channel, when they develop themselves freely, they measure about from 13 feet to 16 feet 6 inches from the base to the crown; in the Bay of Biscay, from 19 feet 8 inches to 23 feet; in the Mediterranean, from 9 feet 10 inches to 13 feet 2 inches; and in the Lake of Geneva, they measure about 8 feet 6 inches. Immediately opposite Southampton the waves attain 7 feet in height, and in some of the wide still-water reaches of the Seine, close to Paris, the waves are occasionally as much as 2 feet 6 inches from the base to the crown. According to Brémontier, ordinary waves have a length equal to four times their height.

From the effect of the pressure of the wind upon the sides of waves during storms, they assume frequently an inclined position. The percussion of such waves upon a shelving shore must be much greater than that of waves whose axes are vertical; because, independently of their inclination, they are usually animated by a very considerable velocity. Should the wind suddenly acquire a great intensity, and its direction (which, as before stated, is slightly inclined to the horizon) coincide in plane nearly with that of the waves, whether it be in the same direction, or in an opposite one, the surface of the sea will be covered with small breakers on every side.

M. Virla infers from his observations at Cherbourg, that the duration of an oscillation augments with the length of the waves, and the depth below the surface to which the oscillation extends. The velocity augments with the length, but diminishes with the depth of the agitation; whilst both these expressions are independent of the height of the undulation. It would thence appear that, in waves whose height is small, and which are of great length, the agitation might descend to rocks placed at a great distance from the surface. And it is also to be observed that, if the undulation of the sea meet any reef or rock, either vertical or inclined to the horizon, above the point where the agitation ceases, or if the reef

or shore occur near the bottom of their visible depressions, a series of variable effects are produced, which depend principally for their mode of action upon the direction of the shore with respect to the prevailing wind of the particular locality.

There are some anomalous effects produced by the percussion of waves, which are of great importance in their bearing upon the form of hydraulic works. Thus Brémontier mentions that the existence of submerged rocks, at from 30 to 40 feet below the surface, augments the height of waves occasionally as much as from 7 to 10 feet, whilst, under other circumstances, breakers will not be formed upon rocks only 20 feet below the water. Again, it is known that if the entrance to a large basin be narrowed by means of bodies floating in such a manner as to be about from 8 inches to a foot above and below the water-line respectively, the sea in the passage will become much more agitated when the waves arrive perpendicularly to the narrowed channel. The explanation of this phenomenon appears to lie in the interference which takes place between the direct waves and those reflected from the sides of the entrance, and the effect of this interference will be either to increase or diminish the extent of the undulation, according as the directions of the two waves coincide or not; but it only modifies the height, without producing any effect upon the length of the waves. Possibly it may be in this manner that we may explain the fact that the waves of the Mediterranean, which are so much shorter than those of the Atlantic, are often quite as lofty; for the reflection of the waves from the shore may be sufficiently powerful to affect their height, whilst the surface is not of sufficient width to allow of the formation of very long waves. Should the narrowing of the channel produce any serious interference with the length of the waves, they will break, and produce a very agitated and chopping sea. The same effect is also to be observed when the bottom or the shore is covered by a series

of rocks projecting above the line at which the superficial agitation ceases to be felt.

When a reflected and shortened wave, such as those just mentioned, meets a large wave coming in from the open sea, a violent reaction takes place, a little to the seaward of the obstacle giving rise to the interference. This is called the *ground-swell*, the " ressac " of French engineers; and it is observed that it ceases to be felt at a distance of about half a mile from the obstacle, and to be the most powerful in narrow lakes bounded by abrupt sides. Moreover, the effect of abrupt vertical obstacles to the further progress of waves, when they are partially immersed and partially above the water-line, is, to increase the height of the waves by the reflection produced by the immersed portion. At the same time, should any part of the wave rise above the upper edge of the obstacle, it will continue its original forward motion, but with considerably augmented velocity.

If the waves, instead of meeting a vertical obstacle, strike upon a gently inclined surface, about the depth of the agitation, the horizontal transmission of the pressures will be modified. It has been demonstrated, theoretically and practically, that the ascensional force of the water will be increased; that the summits of the waves flowing over the inclined shore will rise to a higher point than they would do if the shore were abrupt; and that this excess of height would increase from one wave to another, until the last one will present a nearly vertical side to the shore at the moment of its breaking. The return wave meeting the next incoming one, renders the outline of the latter still more precipitous, towards the shore at least.

Brémontier was led to believe, by the results of some experiments, that the maximum height attained by breakers corresponded with a plane inclined at an angle of $22\frac{1}{2}°$ with the horizontal line; but Reibel is far from admitting that this result is to be received implicitly. All that is absolutely

known upon the subject is, that the excess of the ascensional height of the waves upon an inclined surface, increases in the same proportion as the rate of inclination with the horizontal line (at which it is zero) up to an angle, hitherto undetermined, corresponding to the maximum; and that thence the increase of height gradually returns to zero, in proportion as the plane approaches the vertical line, leaving out of the account, in this latter case, the effect produced by the reflection of the waves. On many natural beaches, and in hydraulic works, the slope of the shore terminates in the upper part in an abrupt face, either with or without any filling in of the angle. An accumulation of all the above effects may follow from such a form, and vary in every particular case, according to the combined action of the tides, winds, and currents upon the waves. When these are driven into internal angles, either of the shore or of the works, and are there again reflected, they attain an additional height. Some authors also suppose, that the elasticity of the air drawn under the crest of the wave, may add to the reaction produced independently by the solid obstacles.

When a separation is placed in a basin of any area perpendicularly to the direction in which the waves advance, the outer portion, in the immediate vicinity of the separation, will be more agitated than before, on account of the interference with their propagation, whilst the second portion behind the separation will be rendered calmer. This effect would take place, even if the obstacle were capable of being submerged; but it would be far more perceptible if the separation should be surmounted by a wall, or some other means by which the action of the wind upon the interior portion of the basin might be obviated. Should the separation, instead of being continuous, consist of a series of open spaces, each space would become the center of new undulations in the second portion of the basin; but they would diminish in height with a rapidity the greater in proportion as the openings were less, compared to the dimensions of the zone of

water behind them. In such cases, however, the agitation of the sea is much increased within the spaces themselves. It is upon this principle that piers or breakwaters formed of open stockades, or of piles, produce still water upon their sheltered sides, when they are placed transversely to the direction of the waves, as in the case of Yarmouth, New Haven near Edinburgh, Ostend, and Cronstadt.

If a species of channel be continued beyond the supposed openings in the separation, whose direction corresponds with that of the principal waves, and whose width is nearly equal to that of the opening, the waves from the outside would continue their original course up this channel, until its friction had destroyed their progressive motion. The rapidity with which this effect is produced depends upon the shape of the channel, and would be the least if it were continuous and insubmersible for the whole of its length. A series of pools spreading out from the sides of the channel, and presenting shelving shores, would accelerate the destruction of the waves. It is upon the various principles involved in these supposed illustrations that the construction of jetties, whether solid or open, have been based; and they have been adopted after a long series of practical observations, confirming the theoretical deductions of such authorities as Brémontier, Sganzin, Telford, and the very distinguished engineers of southern Italy.

The destructive action of waves upon the sea-shore may be easily understood, if we consider the mass of water they set in motion, and the velocity they frequently impart to it; this has on some occasions been ascertained to be even as much as 70 feet per second. Messrs. Virla and Minard cite some interesting facts observed at Cherbourg and Algiers, which appear to prove that the limit of the power of communicating lateral motion in the greatest tempests, is nearly equivalent to an effort of 7865 lbs. per yard superficial. Mr. Stevenson states that, from experiments made on the west coast of Scotland, in positions exposed to the whole fury of the Atlantic, it appears that the average pressure of the waves

during the summer months was equal to 611 lbs. per square foot; whilst in the winter it was 2086 lbs., or three times as great. During the storm of the 9th of March, 1845, it was 6083 lbs.; and on the 20th of November, 1827, the spray rose 117 feet above the mean level of the water at the Bell Rock Lighthouse, so that Mr. Stevenson calculated the pressure of the waves to have been equal to about 3 tons to a square foot. On the western shore of Ireland, Lord Adair has measured rolling breakers not less than 150 feet high; and Sir C. Lyell mentions, to illustrate the transporting power of waves, that upon the shores of the Shetland Islands, in the year 1818, a block, containing rather more than 325 cubic feet, and weighing probably about 23 tons, was transported to a distance of 30 feet, and there broken into fragments. At Algiers, blocks of concrete of about 354 cubic feet in volume, and a specific gravity of 2·2, were torn from their positions, and carried a considerable distance. One of the concrete cones made by De Cessart for the breakwater of Cherbourg, which contained about 445 cubic feet, has, however, resisted all the storms of the Atlantic since the year 1808. We may there-fore assume, with tolerable confidence, that a mass of about 450 cubic feet in volume, with the specific gravity of con-crete, would be the minimum size which could be exposed to the action of the ocean without fear of its being removed. But these remarks must not be considered other than as indicating approximative results; because, in the calculations upon which they are based, no allowance was made for the diminution of specific gravity arising from the various bodies being entirely immersed, nor were the conditions of the friction upon the beds carefully ascertained.

The inequalities of the slope of a shore diminish the movement, the velocity, and the height of waves, and the maximum of the intensity of their action is usually found to correspond with the level of the half tide, or the mean height of the sea; but there appear to exist some anomalies with respect to the last law. Thus, at Cherbourg, the rough

slope at the foot of the breakwater was found to diminish
the violence of the waves, and the maximum effort took place
at the level of half tide, or between 10 and $13\frac{1}{2}$ feet from
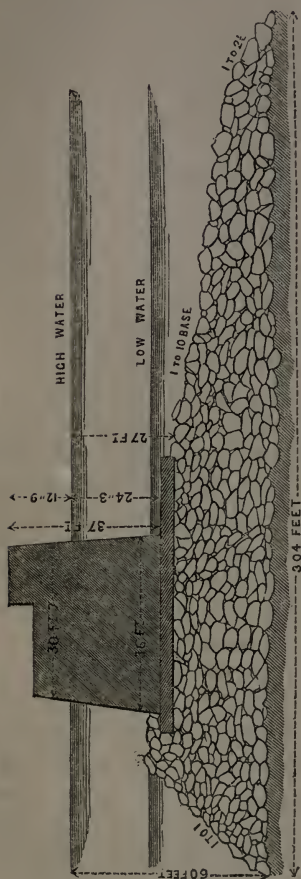
Cherbourg Breakwater.
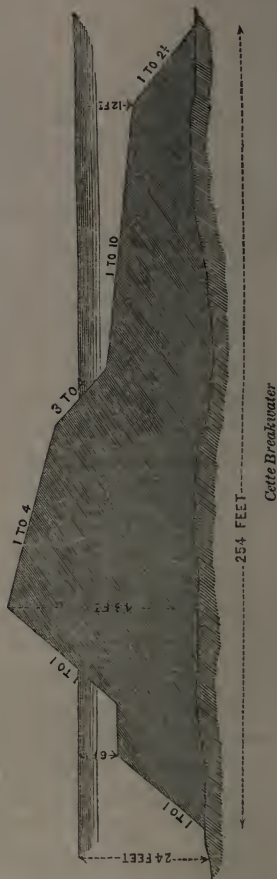
Cette Breakwater.

the top of the wall.   But at Cette, the maximum effect
took place at 5 feet below low tides, upon the breakwater
itself, whilst upon the seaboard the line of action lowered to

about 21 feet below low water, and on the inland side to about 15 feet from the same level. A sketch of the transverse section of the Plymouth Breakwater is added in this
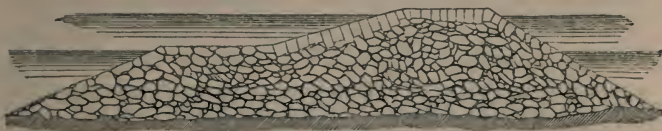
Plymouth Breakwater.

place, in order that it may be compared at once with some of the other most important works of the same description hitherto executed.

Tides*.

The action of the tides upon a sea-shore, or upon any works erected within their range, is a source of great destruction. Tides arise from the periodical elevations and depressions of the sea, caused by the combined attractions of the sun and the moon, and they are the most perceptible in the largest bodies of water. In the Pacific they are greater than in the Atlantic; in the latter, again, they are far greater than in the Mediterranean; whilst they are almost imperceptible in smaller seas, such as the Black Sea or the Caspian.

The waters of the sea rise and fall twice in each consecutive interval comprised between the returns of the moon to the upper meridian. The mean interval of these returns is 1·03505 day, so that the mean interval between two successive high tides is 0·517525 day; the mean time of the low tide dividing this interval again into two nearly equal portions. As in the case of all quantities susceptible of a maximum and a minimum, the increase or diminution of the tides towards such limits is proportional to the squares of the time elapsed between the high and the low tides.

The rising tide is known by the special name of *the flood;* the falling tide, by that of *the ebb*.

* See Newton, Laplace, Whewell, Airy, Lubbock, Mounier, &c.

The height of the full tide varies every day, and the rate of variation depends upon the phases of the moon. The rise is greatest at the syzigies, when the moon is either in conjunction or in opposition; it is least at the quadratures. In the former case, the attractions of both the sun and moon combine to raise the water; in the latter, they mutually counteract one another. But it is to be observed, that the period of the highest tide at any place upon the eastern shore of a continent does not correspond exactly with the syzigies, for Laplace and Whewell have observed, that the highest tides at Brest followed the syzigies at an interval of 36 hours, and those of London at an interval of $2\frac{1}{2}$ days from the same period. So that if the tide were high at the moment of the syzigy, the third tide following it at Brest, and the fifth at London, would be the highest. The difference between the epochs of highest tides at various points, appears to be owing to the time required for the westerly passage of the great tidal wave from the ocean.

The height to which the sea rises at high tide is exactly proportional to its fall at low tide; but there is an irregularity between the two tides of the same day. The *total tide* is therefore ascertained by taking the sum of the heights of the two sides above the intermediate low tide, and dividing it by two. At Brest, where observations have been carried on for the longest period, the total tide at the syzigies is stated to be 15 feet 10 inches, and in the quadratures it is but half that quantity.

The tides occurring at the syzigies are called the *spring tides;* those occurring at the quadratures are called the *neaps.* The former are much increased when the moon is in perigee. An augmentation also takes place at the time when the sun's declination is zero, or at the equinoxes; and the greatest tide occurs when a new or full moon happens near the equinox whilst the moon is in perigee, and her action is still further increased if her node coincide with the perigee. There are other variations in the heights of the

tides, arising from the movements of the sun and the moon, which are continually making the circuit of the heavens at different distances from the plane of the equator, on account of the obliquity of the ecliptic and the inclination of the lunar orbit. These combined motions cause great irregularities in the tides, so that both the time and the precise height of the high water are perpetually changing.

Laplace observes, that the height of the tides depends also very much upon local circumstances. Thus the tidal undulation confined within a narrow strait may become considerably increased, and the reflection from the opposite shore may also augment it to a great extent, especially in the internal angles of the same coast; and it is on this account that the rise of the tide, which is so small on the shores of the islands in the Great Southern Ocean, becomes so great in the ports upon the eastern shores of the Atlantic. High winds, and especially the equinoctial gales coinciding with the spring tides, may also give rise to great irregularities in their heights.

The Governments of most civilized nations publish an almanac of the normal heights of the spring tides at the most important positions upon their shores, which heights are deduced from astronomical observations. It is usual to accompany these tables with a column of numbers called the coefficients of the other minor ports, by means of which it is easy to find the height of the tide in any one of the latter, by multiplying the unity of the tide by the coefficient assigned to that particular port. The unity is to be ascertained on the days immediately after the syzigies of the equinox.

What is called the *vulgar establishment* of a port is the time elapsing between the hour of the full moon at the syzigy and the high tide occasioned by it; and the astronomical tables contain a series of the establishments of the principal ports of Europe. The corrected establishment is the lunar hour of high water freed from the semi-menstrual irregularity,

for the interval of the tide from the moon's transit is affected by a considerable inequality, which goes through its period twice in a month, depending on the moon's distance from the sun in right ascension, or on the solar time of the moon's transit. A simple, but not very exact, way of ascertaining the hour of high tide consists in adding to the hour of the vulgar establishment of a port as many times 48 seconds as there have elapsed days from the full or new moon. It is, however, to be observed that, although the astronomical reasoning with respect to the tides has been demonstrated to be correct beyond all possibility of doubt, yet there are local and occasional irregularities which modify the results of the tidal movements to a great extent. For instance, storms blowing from the sea have sometimes such power, that the tides of the quadratures are raised up by them to heights exceeding those of the syzigies.

Smeaton mentions that, at the port of Christchurch, in Hampshire, the neap tides rise as high as the spring tides when the wind is blowing hard from the west; and the same phenomenon has been observed at Dunkirk. But the memorable storm of Nov. 23, 1824, occurred at the syzigies, for the new moon had taken place on the 20th. The tide, on this occasion, rose at Plymouth nearly 8 feet 6 inches above its usual height at spring tides; the calculated coefficient for the day having been 0·89, whilst the coefficient for the tide which did occur was 1·13. In regard to hydraulic engineering, however, the coefficient to be derived from these extraordinary tides is of little use as a means of ascertaining the height to which marine works may be affected, because the same wind which causes them to rise beyond their usual level at the flood, causes them also to fall to a correspondingly lower level at the ebb; whilst the coefficient only refers to the difference between the tides, without furnishing any definite indication as to the height to which the flood may rise. In the present state of our knowledge there are, in fact, no means of predicating with certainty the possible

influence of the wind upon the rise of the tides. In seas, such as the Mediterranean, where these are but feeble, the winds have a greater disturbing power, however, than in the ocean; and it has been observed that the tides upon the southern coast of France, which are usually from 6 inches to 1 foot, are sometimes carried by storms, at very irregular intervals, to a height of 3 feet 6 inches.

On account of the configuration of the land, the tides, as was before observed, rise much higher on the shores than they do in the open sea, where they are only affected by the attractions of the sun and the moon. The most remarkable variations known are considered to take place at Chepstow, where the rise of spring tides is about 60 feet; at Bristol it is 40 feet; in Mount St. Michael's Bay, it is 46 feet; in the Bay of Fundy and on the coast of Nova Scotia it is about 50 feet; whilst in the Northern Atlantic it is on the average from 10 to 12 feet; at St. Helena, only 3 feet; and on the shores of the islands of the Pacific it is barely perceptible.

The propagation of the tide in rivers partakes of the movement of waves or breakers upon an inclined shore. They rise to a higher point, and continue to a later period, in the interior of a country than they do at the mouth; but the height to which they rise depends greatly upon the outline of the banks of the river; and it appears that the strength and direction of the wind has a greater influence upon the tides of rivers than it has upon those of the sea-shore. In the Elbe, at Hamburg, for instance, with a strong north-east wind the height of the spring tides may be doubled or even trebled.

Theoretically, the time employed by the sea to rise through the different portions of the tide will be represented by the length of the arcs of the circumference of a circle, whose vertical diameter should be the total rise; the arcs being comprised between horizontal lines drawn from the extreme points and corresponding points upon the vertical line, so that the half circumference will represent the total time

between high and low water. The disturbing causes in the immediate vicinity of the sea-shore are, however, so numerous, that it is necessary to make particular observations at every locality where it may be required to construct works exposed to the influence of the tides.

Thus, at Rochefort, near the mouth of the Charente, a double high tide is formed for about three days in each quadrature, somewhat in the manner represented in the sketch in the margin, in which the abscissæ represent the times between the variations, and the ordinates the heights *. In the Orwell, on the Essex coast, as many as four floods have been noticed in one tide; but perhaps two of the most remarkable and interesting illustrations of the disturbances superinduced by peculiarities in the form of any coast are to be found on the southern shore of England, between Portland Race and Selsea Bill; and on the coast of France, a little to the south-east of this district, at the mouth of the river Seine.
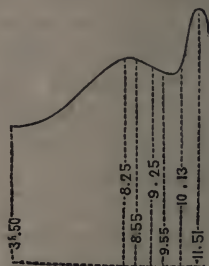
At the western extremity of the British Channel the great tidal wave from the Atlantic rises with considerable regularity on both shores; but, as might be expected, the line of equal, or rather isochronous, tides assumes a convex form towards the east, on account of the diminution of velocity of its edges from the friction upon the shelving coasts. At Exmouth and St. Malo we find that the rise of the tide takes place with great regularity, and in accordance with the deductions from theory, as may be understood by reference to fig. 1, which represents the curve of the tide at Exmouth, at the springs. At the extremity of the Bill of Portland the same law prevails, and the rise and fall of the tide are as nearly as

* It has been found, however, necessary to insert the *times* upon the lines of the ordinates, because the spaces upon the chord-line were too small to receive them in the latter portion of the curve.

possible equal in time. The tide-wave continues its course,
and the northern edge at length meets the Needles Point,

Fig. 1.   Fig. 2.   Fig. 3.
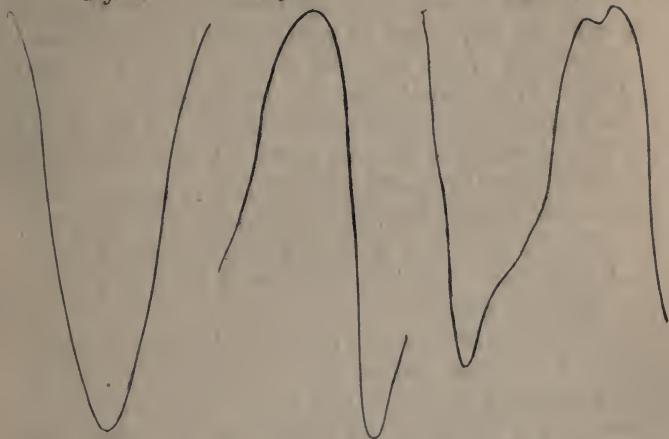
where it divides into two unequal portions, one of which
continues its course round the Isle of Wight, and the other
runs up the Needles passage into the Solent. The velocity
of this smaller tide-wave becomes diminished considerably
(owing to the greater comparative influence of the friction
upon the diminished volume), so that it only reaches South-
ampton at the same time that the mid-channel tide reaches
the point near Dunnose. The small tide-wave then begins to
fall in the Southampton Water, but it is stopped in its descent
by the incoming tide derived from the main mid-channel
stream which flows through the wide and deep passage of
Spithead, and, being driven back, the second high tide, repre-
sented in fig. 3, ensues.

The Spithead tide in its turn divides at Calshot Castle,
and, as it were, superposes itself upon the ebb tide for a con-
siderable distance along the coast. At Yarmouth, the curve
produced is very similar to that noticed at Southampton, whilst

at Calshot Castle and at Lepe the two waves are so nearly identical in time, that the effect of the Spithead tide is only perceptible by the existence of a species of flattening of the curve. At Poole and Swanage the superposition of the Spithead tide upon the ebb, instead of taking place immediately after the high water of the first tide, is to be observed at about mid ebb. In Weymouth Bay, the same phenomenon occurs, but at a period intermediate between the base of the ebb and the commencement of the next flood; and at the Shambles, the last trace of the Spithead tide-wave is to be found in the strong current which flows, at the commencement of the ebb, in a direction from east to west, in direct opposition to the great tidal current, which at that period flows from west to east, or up the Channel.

Smeaton noticed the double tide, above described, at Christchurch; but we are indebted to the careful and remarkably skilful researches of Captain Sheringham, R.N., published in the "Nautical Magazine" for August and September, 1851, for the means of explaining this peculiar apparent anomaly in the tidal action upon our shores. It will be necessary hereafter to recur to this subject, in order to explain the practical influence of such phenomena upon engineering works.

On the French coast, and particularly in the Bay of the Seine, the high water is maintained for a longer period in the several ports of the embouchures of the rivers, than it is in the portions of the channel where the main tide-wave is sufficiently powerful to act in a normal manner. Thus, the tide remains at the full for the space of one hour at the embouchure of the Orne, and for $1\frac{1}{4}$ hour at the embouchure of the Seine; whilst at St. Malo, Dieppe, and Fécamp, it commences falling directly the culminating point has been attained. In these cases it appears that the impetus of the main ebb-tide wave, arising from its volume and velocity, is sufficient to prevent the escape of the small portions which had found their way into the irregularities of the coast, until

the level of the main stream had so considerably fallen as to allow the superior elevation of the in-shore waters to overcome the resistance of the main stream.

It must be observed that the outline of the ocean, upon the shores at least, is very far from being of the simple character it is usually considered to be. Not only is it modified by the tides, but also the latter are in their turn much affected by the configuration of the land. Thus, in the Bay of Weymouth, the great tide-wave sweeps past with great velocity, and it is only by what may be called derivation from the main stream that the water in the bottom of the bay is affected; and, in fact, at some periods of the tide, the water rather flows with an easterly current than in the ordinary westerly direction. If it were possible to level the mean surface of the tide-wave, we should, in all probability, find that a line would exist, passing from the extremity of the Portland Bill to St. Alban's Head, upon which the water would, during the flood-tide, occupy a ridge at a sensible elevation above that in the interior of the bay between those points. It must, indeed, be evident that the water, when once impressed with the motion of the tidal wave would, from its inertia, continue to follow its path in the direction thus given, until the superior force of gravity should cause it to flow into the lower positions withdrawn from the direct influence of the tide. Upon the tides in the Bay of the Seine this action is also very manifest, and the high ridge of the tide sweeps by the indent of the land, from the Cap de Barfleur to the Cap d'Antifer. In the intermediate portions the rise of the tide is only derived from the main stream, excepting at the mouth of the Seine in front of Havre; for the tide striking upon Cap d'Antifer divides into two portions, one of which continues up the channel, and the other returns along the shore, passes in front of Havre, and, joining the derived tide, runs up the Seine. On its course, however, this in-shore current is deflected by the jetty at the mouth of the port of Havre, and is carried on to the Point du Hoc, where

it again divides, one portion flowing up the river, and the other returning close along the shore until it flows into the outer harbour.   There are, in fact, no less than three strong tidal currents flowing in front of the port of Havre, each of which has a direction opposite to that of the current more towards the open sea than itself.

Finally, it is to be observed with respect to the tides, that they are so influenced by the outline of the shores and by the reigning winds, as also occasionally by local currents, that no abstract reasoning can be applied to them.   As the relations between the times and the heights of the tides are of incalculable importance, both to the engineer and the navigator connected with any port, it is impossible to obtain too much information upon the subject.   It would be, therefore, of the highest interest were consecutive observations carried on at all the important points of our coast.

Currents *.

The stability of works erected upon the sea-shore is often affected, directly or indirectly, by the action of currents ; and the remarkable influence they possess upon the direction of alluvions, sand, or shingle, renders their study the more indispensable.   Some of the most striking illustrations of the importance and nature of currents are subjoined.

In the Mediterranean there is a general current flowing along the shore, near the western end, whose direction is from the west to the east on the coast of Africa, and from the east to the west on the coast of Europe.   On the French coast the velocity of this current does not exceed 3 inches per second, whilst at Algiers it has been noticed to flow at the rate of from 10 to 12 inches, or even as much as 40 inches, per second, at the extremities of some capes.

The oceanic currents are of much greater importance than that of the Mediterranean, on account of the immense

* See Rennell on Currents ; Sganzin, Minard, Rennie, &c.

volume of water they roll along, and of their velocity; as likewise of their greater influence upon the climate of many portions of the globe, and the serious interference they exercise upon the operations of sailors. The Atlantic currents are those with respect to which we possess the most accurate information; and, indeed, it is probable that Major Rennell's surmise may be correct, that the outline of the shores of the Pacific is not so calculated to give rise to them as those of the Atlantic. The most important of the currents in the latter is the great Gulf stream, which sets round the Cape of Good Hope from the Pacific, along the western shore of Africa, until it meets the Bight of Benin, by which it is deflected to the opposite coast of America. Striking the extreme eastern point of that continent at Cape St. Roque, it continues along the American shore to the head of the Gulf of Mexico, from which it flows through the Straits of Florida, following the eastern shore of the northern continent for a short distance, and a little below Newfoundland it turns off abruptly to the eastward. The main body of the Gulf stream is then deflected towards the south, and is lost near the Azores; but an important branch sets towards the direct east, and runs round Ireland and England, finally losing itself in the Arctic Ocean, near Spitzbergen. The effect of this stream is decidedly to contribute to the mildness and moisture of the climate naturally arising from our insular position.

On the western coast of France a current takes it rise, which flows in a southerly direction, along the coast of Africa, having, in its course, given off the stream before noticed as flowing into the Mediterranean: it is finally lost in the Bight of Biaffra. Major Rennell also was of opinion that a similar current also took its origin in the Bay of Biscay, and flowed in a north-easterly direction round the British Islands. It is, however, doubtful whether this be not merely the branch of the great Gulf stream already noticed.

The progression of the tide-wave creates a current, whose

direction, when observed near the shore, is very variable, although, as a general rule, it will be found to alternate, like the cause which gives rise to it. But it would appear that the change in the horizontal direction of the current by no means coincides invariably with the vertical change of the tide in time. There is an interval, more or less long, between the reversal of the direction of the current, and the epochs of the full or the low tide; and the coincidence, when it does occur, appears to be owing to some local and exceptional circumstance. Again, in some positions the direction of the tidal current varies through nearly all the points of the compass within the day (as, for instance, in the channel between Jersey, Guernsey, and the French coast); in other cases the variation only extends through a portion of the circle; whilst the normal change is only in the precise direction of the ebb and the flow.

As the principal lines of the tidal currents thus coincide with that of the progress of the great tidal wave, it must be evident that they would vary on each shore of the British Islands. On the southern shore they are principally from the south-west to the north-east, and *vice versâ*; on the western coast they are from S.S.W. to N.N.E., and *vice versâ*; on the eastern coast they are from N.N.W. to S.S.E., and *vice versâ*; which directions continue until the tide-wave which has passed round the northern part of Scotland and continued down the eastern coast, meets the tide-wave which has passed along the southern shore. But the influence of the configuration of the land upon the directions of currents is very perceptible in the shallow seas surrounding the British Islands; and it is therefore in similar positions more important to observe the nature and effects of local currents, than to adopt implicitly any merely abstract theoretical deductions. The peculiar laws of the tides, already alluded to as prevailing upon the coast between Portland Bill and Selsea Point, and in the Bay of the Seine, may be cited as instances of the modifications the outline of a coast is able

to produce in the direction of the tidal currents. Upon the southern coast of Great Britain another cause of irregularity exists in this, that the continuance of the south-west wind for a lengthened period will cause the tide to flow for an hour longer than usual, and in this manner give a preponderance to the direction of the current in the direction of the flood over that of the ebb.

The velocity of oceanic currents is not affected by the movement of the waves, for the advance of floating bodies within their influence takes place as rapidly when the sea is agitated as when it is calm; but the wind has very considerable power upon them, especially in their upper portions. It is also observed that occasionally there is a difference of direction between the upper and lower strata of currents, which may in all cases be accounted for by the interference of some local disturbance. The rate of flow varies within very considerable limits, as may be perceived from the following list of some of the most remarkable currents hitherto observed.

	ft.	in.	ft.	in.	
At the Ile d'Yeu, off the coast of La Vendée	1	8			per second.
At the harbour of Lorient . . .	3	4			,,
,, ,, Cherbourg .	4	8			,,
Off the coast of Alderney, sometimes	11	6	to 14	6	,,
,, south coast of England .	5	0	to 10	0	,,
,, entrance to the port of Hâvre	5	0			,,
,, ,, ,, Dover .	6	6			,,
,, ,, ,, Calais .	7	10			,,
,, ,, ,, Dunkirk .	4	8			,,
,, coast of the Orcades Islands	13	0	to 14	8	,,

The effect of the interference of any irregularity of the outline of a coast upon the direction of the currents is to produce a series of counter-currents, eddies, and whirlpools. It is admitted, therefore, that any abrupt projection or retreat from the general line, either of a current or of the bed of a river, will give rise to such counter-currents, whose destructive action upon the obstacles causing them will

have the greater intensity, in proportion to the greater velocity of the stream. Capes, bays, and islands are the natural means by which these effects are produced on a large scale. The jetties at the mouths of harbours have a precisely similar action; and the changes they reciprocally produce upon the normal direction of the main currents require to be carefully studied, both by engineers and pilots.

At the embouchures of rivers the effect of the disturbing causes is further complicated by the dynamical tendency of the water of the current to flow into the depressions always existing in such positions at low tides, and by the descent of the upland soft waters. The form of the embouchure has considerable influence upon the phenomena to be met with in any particular instance; for it may happen, and sometimes does, that even when the tide falls, the sea water will continue to be poured into the river; or *vice versâ*, that the river will discharge into the sea after the tide has commenced rising; inasmuch as the conditions of the interchange of the waters depend upon the configuration and size of the passage. Thus, at the mouth of the Adour, a river which, instead of being open towards the sea, has a funnel shape with the neck outwards, the tidal wave maintains a greater height in the sea than in the river during the whole of the flood, because it cannot enter through the narrow mouth with sufficient rapidity to fill the bed of the river. The difference of height has been noticed to be as much as four feet during the syzigies; and, in consequence of it, the duration of the flood-tide in the interior of the Adour is prolonged for about an hour after it has ceased in the open sea. Analogous effects have been observed at the mouth of the Tay, in Scotland, where also the embouchure is suddenly contracted.

A very peculiar and interesting phenomenon, before alluded to, may be observed during the rise of the tide in rivers. In such cases, as the molecules of the water pouring into the river are impressed with a velocity equal to that of the great tidal wave, their direction whilst flowing into the river will

evidently be a resultant from the two directions of their original flow, and that arising from the tendency of the water to fill up the depression of the embouchure. In the center of the principal current there will then be formed a line corresponding with the axis of equilibrium of the forces attracting the water up the river and towards the side. This remarkable line is sometimes sufficiently defined to be visible to the naked eye; and at all times it may be distinguished by a broad sheet of stagnant water on either side; but it necessarily changes, both in its direction and its form, according to the state of the tide, or the nature of the bed of the river. A precisely similar effect we have seen to take place during the rise of the tide in certain bays; as in the cases before cited of the Bay of Weymouth and of the Seine; but its mode of action may be more distinctly observed in rivers.

The descending fresh water interferes with the transmission of the tidal wave up a river in the following manner:— As soon as the flood begins to pour in it creates a species of dam, opposing the descent of the fresh water. Until the sea has attained a greater height than that of the water so accumulated, it cannot flow into the river; but as the rise of the tide is usually much more rapid than that of the land-waters, its effect becomes quickly perceptible. In the mean time a series of zones of still water, of eddies, currents, and counter-currents, will be formed, in consequence of the opposite directions of the flow of the two waters, and of the difference in their specific gravities; and these irregularities will assume a greater importance, and a more permanent character, in proportion as the volume and the velocity of the descending fresh water is more considerable; and they will continue until the tidal wave shall have entirely overcome the resistance of the downward current of the river.

It is on account of the interference of the descending fresh water with the transmission of the tidal wave, that the hours of the flood and the ebb tides are retarded in propor-

tion as the distance from the sea increases; at the same time, however, the species of heaping up produced in them augments the difference of level. Indeed, from this cause it frequently happens that in the interior the tide rises to a point considerably above the level of the high tides in the ocean.

But the most singular phenomenon connected with the rise of the tide in rivers is the one presented by the " bore." According to Colonel Emy, this may be defined as being a peculiar undulation, which announces the arrival of the flood-tide in many rivers. It consists of two, three, or sometimes four waves, very short, and succeeding one another rapidly, which bar the whole river, and ascend it to a great distance; they often break upon the crown, and upset everything they meet in their course, and are accompanied by a fearful noise. In the Severn, the bore is stated to be of almost daily occurrence, and sometimes even to attain a height of 9 feet; in the Dordogne, it rises from 5 to 6 feet, and travels at the rate of about 5 miles in 34 minutes; in the Seine, it does not exceed 3 feet; in the Thames, it only exists in a rudimentary state; whilst in the Hoogly, at Calcutta, it rises about 5 feet, and is transmitted at the rate of about $17\frac{1}{2}$ miles per hour; and in the Menga the rise is said to be 12 feet.

The cause of the bore is universally considered to be owing to the interference with the transmission of the tidal wave, arising either from the sudden contraction of the embouchure of the river, or from the existence of some abrupt step or bar in the bed. The wave terminates abruptly on the inland side, because the quantity of water contained in it is so great, and its motion so rapid, that there is not sufficient time for the surface of the river to be raised immediately by the transmitted pressure. Mr. Whewell compares this abrupt tide-wave to those which curl over and break upon a shelving shore. The periods at which its effects are the greatest are at the syzigies; and they decrease in proportion as the bed of the river is deeper.

Effect of Waves, Tides, and Currents upon Sea Coasts.

The sea-shore, of whatever materials it be composed, if it lie in the direction of any current, whether tidal or of any other description, is gradually worn away by the incessant action of the water. Under normal circumstances there is a singular uniformity in the mode of this degradation; and equally in the cases of hard rock, of agglutinated shingle, or of clay, it will be found that, for a certain height above the level of ordinary calm high tides, the outline of the shore assumes a curvilinear form. Where the sea is much agitated, the height in question may attain from 13 to 14 feet; the curve itself is always cycloidal. At its foot, and tangentially to it, succeeds a slope, which joins the natural bed at the level of the lowest tides, with an inclination varying according to the nature of the beach. Sometimes the slope within the range of the tides is as 7 to 1; and it diminishes as frequently below the level of the low-water mark to as much as 30 to 1. At other times, and especially if the bed be of mud, the slope becomes almost abrupt below the low-water line, because the water supports the mud. At Cherbourg, it was noticed that the small materials thrown into the sea for the formation of the breakwater took a slope of about 45° below that line; and in many cases upon our shores the shingle banks may be observed to assume a similar inclination. In the Lake of Geneva, the shore near Vevay, where it is composed of fine sand, takes a slope of 10 to 1, to a depth of from 6 to 7 feet below the variations of the water-line; whilst, at a greater depth, the slope is as 2 to 1, or the natural inclination of sand in still water.

The destructive action of the sea upon the shores bounding it, arises principally from the action of the waves moving in the direction of the prevailing wind. This action is complicated in its nature, but it may be considered to be

* See Lamblardie, Sganzin, Minard, Smeaton, &c.

composed of the oscillating motion of the molecules of the
water occasioned by the waves; of the effect produced by the
wind upon the upper parts of the waves themselves; of the
reaction produced by any projection beyond the ordinary line
of the shore; of the permanent and periodical currents to
which the mass of the water may be exposed; and, finally, of
the dynamical effort exercised by the water set in motion.
Of these causes, the three first are without comparison the
most powerful, and hitherto it has not been ascertained
within what limits they are able to act.   But it is important
to observe, that the existence of any object in abrupt relief
gives rise to such eddies, that the bottom of the sea round it
will be rapidly carried away, if it be of a nature to yield
easily, and be situated within the limits of the disturbing
causes.   It follows from this, that great precautions must be
taken in the construction of any vertical retaining wall whose
foundations may be near the low-tide line; for the repercus-
sion of the waves is certain to undermine them, if formed in
clay or light sand.

Occasionally it may happen that the destructive action of
the sea, which principally operates in the direction of the
advance of the flood-tide, is reversed by the existence of some
local current which increases the power of the ebb.   Thus in
the British Channel the outline of the majority of the bays
between Land's End and Portland Bill is concave towards
the incoming tide; but between Portland Bill and Selsea
Point, the outline of the bays, of the main land at least, is
almost invariably convex to this tide.   The cause of this
apparent anomaly is to be found in the existence of the
second tide before noticed, which increases the volume of the
ebb close in shore; and also to the fact that the island of
Portland, and the spur terminated by St. Alban's Head, form,
as it were, breakwaters sheltering the intermediate district
from the effects of the south-west winds.

The geological nature of the rocks exposed to the fury of
the waves may also materially affect their rate of destruction,

and also react upon the preservation of the neighbouring shores. In the particular instance last cited a remarkable example of this may be found; for the projecting points of the Isle of Portland and St. Alban's Head are respectively of the harder and more resisting strata of the oolite; whilst the intermediate bays of Weymouth and of Poole are excavated in the less resisting strata of the Oxford, or the London, clays.

Similar observations are to be made upon the configuration of the French coast in the Bay of the Seine. Its general outline is concave towards the north-east, on account, doubtlessly, of the increased force of the ebb-tide, arising from the deflected portion of the flood striking the Cap d'Antifer, and from the volume of the several rivers, Seine, Orne, Touques, Dives, Vire, &c., which pour their waters into it. From the fact also that the western extremity of the bay is formed by the granitic peninsula of the Cotentin, projecting far into the British Channel, this portion is sheltered from the first violence of the great tidal wave, and also from the effects of the prevailing winds over the vast expanse of the Atlantic. Beyond the Cap d'Antifer, as also beyond Selsea Point, the main outlines of the bays resume their normal direction; and they are concave towards the incoming flood-tides. These observations, however, must only be understood generally, because there are innumerable causes of interference with the action of the usual laws, which may be observed to affect variously every particular locality.

The materials detached from the rocks or shores by the sea are transported by the currents in a direction which may be stated generally to correspond with that of their greatest and most permanent influence, whether that be in the same line as the advance of the great tide-wave or in the opposite one. Thus upon the French coast the materials detached from the cliffs, in the portion situated near Cap d'Antifer, are transported partly towards the east, and partly towards the west, in consequence of the separation of the tidal cur-

rent at that point, and the normal direction of the bars at
the mouths of the harbours will be found to correspond with
these directions; that is to say, the shingle enters the ports
of Etretat, Fécamp, and Dieppe, from the west; whilst it is
carried into Hâvre and Honfleur from the east, and the bars
of the Orne and the Vire have a general inclination across
the mouths of the rivers from east to west.   Between Land's
End and Portland the shingle moves from west to east with
the tidal current, and again beyond Selsea Point to the
Foreland the same fact may be observed; but, in opposition
to the generally received opinion, it will be found that the
bulk of the shingle moving along the coast between Portland
and the Needles, moves from east to west, and that the main
direction of the bars is also between those points.   The tidal
currents of this part of our shore are, however, so extremely
complicated, that it is hardly possible to affirm that any
positive law exists with respect to the distribution of the
shingle upon it; and, indeed, the prevalence of a south-east
wind for a few days will totally reverse the ordinary conditions
of its advance.

However, it will be found that, in every possible direction
of the progress of the shingle or other detrital matters, the
current will deposit them upon its concave edge, when it
is deflected by any object from its ordinary path.   This is to
be accounted for by the fact that the mass of water in the
main current will be animated by a certain velocity, which
will carry it forward in its original direction; when, therefore,
it is diverted from its course, the change will take place in a
curvilinear form, derived from the original impulse, and the
tendency to rush into the depression existing behind the
obstacle.   The main body of the stream, under such circum-
stances, will retain its velocity, but the edge near the obstacle
will flow more slowly by the effect of the friction and the
retardation caused by a portion of the water flowing into the
depression.   In consequence of this diminished velocity the
stream will no longer be able to transport the shingle, which

will necessarily be deposited on the line corresponding with the retardation. The Italian authors upon hydraulics have also observed, that when the wind blows in the same direction with that of the littoral current, sand-banks are more rapidly formed in the sheltered parts of the shore than under other circumstances.

The shingle, or other alluvions, which surround the bases of cliffs, follow precisely the contours and directions of the latter in plan. But when the shingle collected in a bay has no extrinsic support, it will assume a curvilinear outline, whose concavity will be turned towards the sea, in the direction of the prevailing wind. This effect may be distinctly perceived in some of the bays upon the eastern shores of England, and upon the French coast between the Caps d'Antifer and Grisnez; for in both cases the yielding nature of the materials allows the general outline of the coast to modify itself to the most powerful action of the waves, which, as is well known, is always exercised in the direction of the prevailing winds. On some parts of the French coast M. Lamblardie found the concavity to be nearly one-tenth of the chord line of the bay. It also appears from his observations, and from those of Zendrini, upon the shores of the Mediterranean, that the advance of immersed substances, and of detrital matter in suspension, may be owing either entirely to the action of the waves, or to that of periodical currents, or to a combination of both. When the direction of the prevailing wind and of the waves is perpendicular to the shore, the corrosive action attains its maximum, but no movement of translation is given to the detritus along shore. When the direction of the wind is parallel to the shore, the action upon the shingle is at the minimum; and Lamblardie asserts, that when that direction forms an angle of 45° with the shore, the action to produce the movement of translation attains its maximum. If, therefore, a bay exist whose central axis should correspond with the direction of the prevailing winds, the alluvions driven along the coast will be accumulated at

the bottom of the bay; and if a projecting mass of shingle should be exposed to such a wind, the materials of which it is composed would be carried from it on either side of its summit.

As might naturally be expected, it is found that if the direction of the littoral currents corresponds with that of the prevailing winds, the advance of shingle or other alluvions is more rapid; and, in fine weather, the translation of the smaller materials may still continue. But if the two forces should be in opposition to one another, there will ensue a diminution, or even a temporary or a permanent cessation, of the onward movement.

If, during their advance along the shore under the double impulsion of the waves and of the currents, the alluvions meet a deep bay sheltered from the prevailing winds, the still water existing in it will allow the heavier particles to subside; and if, in addition to the general comparative tranquillity of the bay, there should exist any subsidiary currents, producing upon their edges zones of still water, the remaining matters in suspension will be deposited either temporarily or permanently. This latter contingency occurs in the embouchures of most rivers, and the bars are formed, in such cases, by the deposition of the alluvions upon the line of junction of the littoral current with that of the down stream; and, as these directions are usually either at right angles, or highly inclined, to one another, the axis of the bar follows that of the resultant affected by the volume, the velocity, and the direction of the two streams.

Should the alluvions, instead of meeting with a deep bay, such as has been described, meet with a projection upon the shore, they will form a deposit in the opposing angle which will be concave to the general direction of their advance. If the action

giving rise to the alluvions be permanent, it will eventually
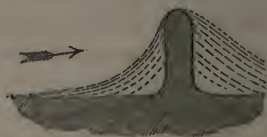
carry them round the projection, and there, meeting with still water, they will be deposited. The accumulation of a bank in this position will often be accelerated by the currents and counter-currents generated by the projection.

The conditions of the advance and deposition of marine alluvions are complicated by many interferences, in the mouths of rivers, beyond those already alluded to. For not only are they affected by the outlines of the coast, and the meeting of the currents, but also by the differences in the specific gravities of the waters, and by the sediments brought down by the rivers themselves. According to the particular period of the tides, there is an alternate predominance in the effective action of the two waters; and the occasional occurrence of land floods still further modifies them, thereby complicating to a much greater extent the phenomena of the formation of gravel or mud banks in what are called the " deltas " of rivers. This subject is treated with remarkable ability in Sir H. de la Beche's " Geological Observer," and the reader is therefore earnestly referred to it; but it may suffice for our present purposes to observe, that long and patient observations require to be made before any engineering works should be undertaken, with a view to modify the conditions of the deposition of the banks in the embouchures of rivers. If, on the one hand, the narrowing the channel be advantageous, by confining the waters in an invariable direction, and by deepening the passage by the increased velocity thus obtained; it may, on the other, also diminish the quantity of water introduced at every tide into the upper reaches of the river, and interfere with the discharge of the floods.

The extent of complication, so to speak, of the causes bearing upon the deposition of alluvions in embouchures is so great, that, in the present state of our knowledge, nothing can be predicated with certainty as to the effect of any modifications upon their outline, whether produced by nature or by art. It seems, therefore, advisable, unless there be some exceptional circumstances attached to the particular

case which may be under consideration, to adopt merely temporary methods of removing the deposit which may obstruct them, rather than to construct expensive works with the hope of controlling the powerful and unknown operations of nature.

In tideless seas, such as the Mediterranean and the Gulf of Mexico, the littoral current is not sufficiently powerful to counteract the influence of the waves and of the reigning winds, or at least it can only carry forward the materials already in motion. The deposits of alluvion in such seas, then, are only regulated by the winds and the waves along the open coasts. In the embouchures, the matters in suspension in the river waters are thrown down gradually, and in the order of their specific gravities, at the points where the velocity of the soft water ceases to be sufficient to bear them along.

It appears to be generally admitted by the Italian, French, and German engineers, that where sand-banks have once begun to form naturally, it would be in vain to endeavour to prevent their continued increase. All their efforts are therefore directed simply to fix such banks as may exist, in the positions where they are likely to be the least injurious, and where any additional accumulation may be easily removed by dredging. At the port of Cette, on the French shore of the Mediterranean, artificial means have been employed to provoke, as it were, their deposition in certain positions, but the result hitherto has been problematical. It appears, also, that the observations of the Italian engineers have led them to the conclusion, that the best position for ports in seas like the Mediterranean, so far as regards their freedom from alluvial deposits, is one in which a natural bay may exist, without a river, or other cause of interference with the current. The bay should also be placed in a direction opposite, not only to the littoral current, but also to that of the prevailing winds.

Some very striking illustrations of the importance of the

effects produced by the alluvions set in motion by the sea, whether they consist of shingle, sand, or silt, may be found upon almost every shore. On the coast of Kent, two deep indentations upon the outline of the land, at Romney Marsh and Pegwell Bay, have been filled in. On the coast of Norfolk, Lowestoff Ness is also gradually gaining upon the sea, from the deposition caused by an interference with the progress of the shingle. In the Mediterranean, the ports of Aigues, Mortes, and of Fréjus, from which the armies of St. Louis embarked, are now far inland, and are only kept open for small vessels by means of constant dredging. The port of Ostium, at the mouth of the Tiber, formed by Claudius and repaired by Trajanus, is now about three miles from the sea. The lagunes of Venice tend naturally to silt up, and are only kept open by means of the artificial channels constructed for the purpose of carrying the waters of the several rivers Brenta, Bachelone, Piave, and the Sile, more directly into the open sea of the Adriatic. Illustrations of the erosions produced by the action of the waves may also be found on every shore; the reader who would desire to study this branch of our subject more thoroughly is, however, referred to Lyell's " Geology," and to De la Beche's " Geological Observer " for further details.

The materials detached from the cliffs undermined in this manner are rolled forward continually, and under the influence of this friction they become comminuted at length to a fine sand. In some cases the sand, earth, and broken shells deposited by the high spring tides are carried inland by the wind, and advance in waves nearly as strongly defined as those upon water. If any obstacle be offered to their progress, they accumulate to a vast height, and occasionally they spread over a great extent of land on either side. Thus, in the Landes of Bordeaux, hillocks of sand are said to have been formed, attaining a height of about 160 feet; and the sands advanced towards the interior at the rate of about 33 feet per annum,

until Brémontier commenced the series of works for the purpose of fixing them which has contributed so much to immortalize his name. In the case of the Landes of Bordeaux, the progress of the sand was accelerated by the dryness of the atmosphere; but upon our own coasts, in Poole Harbour, and on the French coasts, near Dunkirk, the rain-fall, and perhaps also the presence of a considerable quantity of earth in conjunction with the silicious sands, develops a peculiar vegetation which prevents the further progress of these downs, or dunes, as they are called in France and Belgium. The principal measures adopted by Brémontier consisted in planting the sand reed (*Arundo arenaria*) for a distance of about 300 yards from the sea. For a second zone, of about 1000 feet in width, he planted creeping plants, brambles, heaths, &c.; and more inland, at a distance beyond the influence of the salt water, he planted a zone of fir trees. It appears, however, that the fixing the landes near the plains of Soulac and Thalais, on the sea-shore to the south of the Gironde, has produced a considerable effect in the action of the sea upon the outline of the coast. The very incoherence of the sands appears to have prevented their removal, seawards at least.

Defence of Shores.

The foregoing general observations upon the action of the sea upon the coasts, or works exposed to its effects, are necessary to a complete knowledge of the most advisable means to be adopted for their protection. With respect to the defence of coasts, it follows, from what has been said, that the works to be executed must consist either of such as are able to break the force of the waves before they reach the shore; or of such as are able to consolidate the shore itself, so as to enable it to resist more effectually the denudation produced by the waves; or of such means as shall cause an

accumulation of sand and shingle upon the fore shore. Under some circumstances it may be advisable to combine the three descriptions of works.

The construction of groins firmly connected with the shore, and following a direction normal to that of the reigning winds in tempestuous weather, whether they be submersible or not, would diminish the action of the waves; particularly if they be carried out so far as to prevent the species of cascade, which always takes place on their downside, from affecting the shore itself. In some cases isolated pillars of masonry or timber-framing, placed like the squares of a chess-board, by causing the waves to break seawards, may become very efficient means of defence. On the coast of Holland very successful results have been obtained by the erection of wooden framing placed in a parallel direction to that of the coast at the line of low water. In soils susceptible of being easily removed, however, it is indispensable to protect the foundations of these groins by apron pieces.

The consolidation of a shore must be performed in very different manners under different circumstances. If the natural inclination above low-water mark, up to the extreme point reached by the waves during tempestuous weather, be abrupt, it will probably be found more advantageous to interpose a vertical wall or defence, whether of masonry or of wood-work. In the former case the stones should be laid as headers, and the upper parts coped with the largest stones it is possible to procure, also laid as headers; and it would be advisable to pave for a distance of some 8 or 10 feet beyond the coping, so as to throw off effectually any water breaking over the wall.

The footings must also be protected by rubble stone-work, or
by an apron bedded in mortar.

In Holland, however, the dykes are very frequently formed
as represented in the sketches here given, the body of the

Fig. 1.

Fig. 2.

Fig. 3.

HIGHEST TIDE

ORDINARY H. TIDE
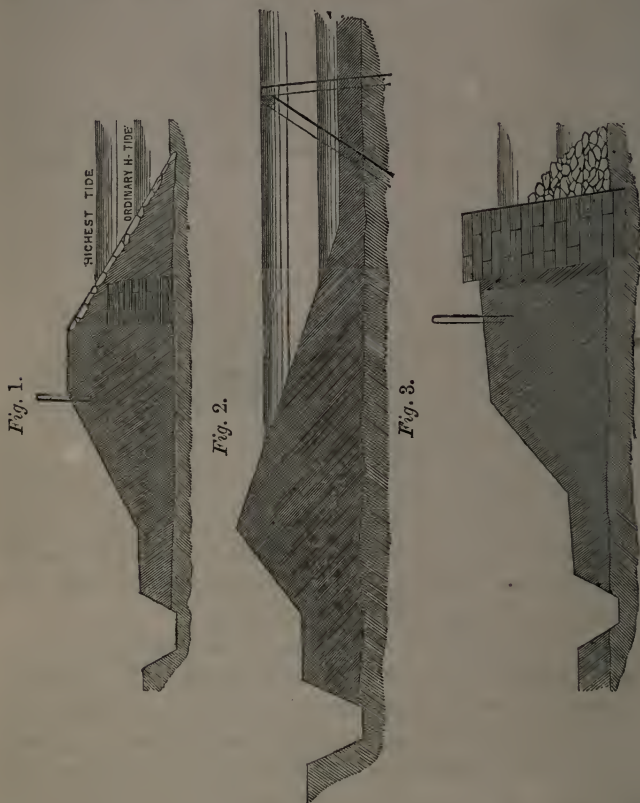
embankment being of earth with a hearting of fascines, or of
bundles of reeds in some cases, or with a facing of similar
materials in others, protected at the foot by rubble-stones.
Or, again, the whole of the embankment may be in earth-
work, with or without any provision to break the force of the

waves. Many instances may be mentioned where the banks
of the polders are formed in a manner similar to a coffer-

Fig. 4.

Fig. .
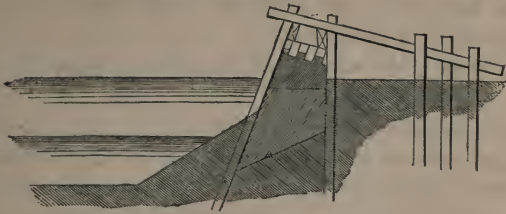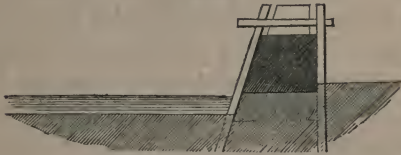
Fig. 6.
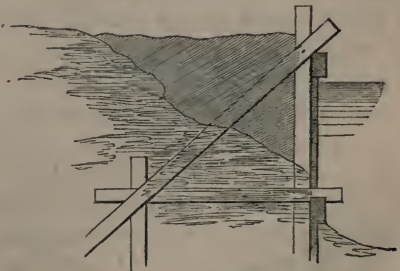
dam, by means of a
puddle-dyke retained
between sheet piling.
At Hâvre, the mode
which proved most
successful consisted
in forming an em-
bankment of earth-
work behind a ver-
tical inclosure of

Fig. 7.

E 3

sheet piling, with a loose rubble apron at the foot, or even, in the positions where the scouring effects of the current were very great, with an apron of solid masonry. The general form of the sea defences of the plains near Hâvre is represented in the sketch fig. 7.

The remarkable success of the dykes formed with long slopes upon the fore shore, in the manner of the Dutch engineers, would seem at first sight to be inexplicable if the principles adopted in such cases as the one cited immediately after them be correct. But it happens in this instance, as in so many others to be encountered in engineering, that circumstances seriously modify the application of purely theoretical deductions. Unquestionably sea walls presenting a vertical face to the action of the waves are more capable of resisting their effort, provided the foundations be good, than when they present a long inclined face; because the sea is, in the latter instance, carried to a much greater height, and breaks with greater force upon the shelving shore, than when its effort is destroyed by a resistance acting more directly in opposition to its own. But the repercussion of the waves dashing against an obstacle of the description of a vertical wall, creates so great a tendency to undermine its foundations, that it appears demonstrated by experience that they only resist when placed at such a depth as to be below the usual range of disturbance by the waves, or upon the condition of repairing them constantly. If a coast, then, be bathed by deep water, and present steep escarpments, the works erected for its defence, as before stated, should be vertical; if the fore shore should present a long slope, the works erected for the protection of the land must be made in continuation of it, adopting as the limit of inclination for embankments in stiff clay 10 on the base to 1 in height, and in loose fine sand as much as 20 base to 1 height.

It is important to observe that, whatever form be given to the embankment, its crown must be carried above the level of the sea during the most disturbed periods; for the water

breaking over the crown softens and carries away the backing, if of earth-work especially, and gives rise to settlements of a very dangerous character.

Owing to some local considerations, it may occasionally be preferable not to form the slope of the embankment with so wide a base. In such cases it will be necessary to protect it with a facing, the materials of which will be regulated upon the simple ground of economy. They may be either of carpentry, of fascines, reeds, or of stone pitching; the most important element in the decision of the question being, that the maintenance should be assured, without danger of interruption. The portion of the pitching or facing corresponding with the plane of the half-tides requires to be strengthened, because it is about that height that the waves and currents exercise their greatest power. Moreover, as the solidity of an embankment can only be depended upon when it is founded upon a rock or upon some stratum able to resist the action of the sea; and as the inclination of the fore shore always depends upon the configuration of the coasts, and the inequalities and nature of the soil in which it is formed, it becomes indispensable that all the variable conditions these are likely to assume should be carefully examined before commencing such works.

Upon the shores bathed by currents carrying much alluvial matter, it is possible to retain this by means of groins raised above the high-water line, or by shingle traps, or by groins submersible at half tide. The effect of these constructions will be precisely analogous to that of the supposed obstacle to the onward movement of alluvions before described; the shingle will be accumulated on the up side of the groin (that is to say, in a direction meeting that of the current) until it has filled in the angle. It will then pass round the point and accumulate in the still water behind the groin on the down side. A curious effect is, however, often produced by the erection of these works, viz., that the corrosion of the shore takes place with greater violence beyond the point

where the protective influence of the last groin is felt, than it possessed previously to their erection. The materials to be employed in the construction of groins should be of the most economical nature, as they are rarely intended to occupy their positions permanently.

Construction of Piers and Breakwaters.

The construction of piers, jetties, and breakwaters, is much influenced by the considerations of the effects of winds, tides, and currents, above described. The objects they are proposed to effect are to procure tranquillity in the interior of ports, and at the same time to facilitate the manœuvres of shipping entering or leaving them. To explain the details connected with such works, it becomes, therefore, necessary to dwell somewhat at length upon the general character and description of ports to which they form such important adjuncts.

It is usual to designate by the term " port " a space of water in connection with the sea, of variable dimensions, and of depths either constant or variable, in which ships may obtain shelter from tempests or from an enemy, repair any damage they may have received, or discharge and replace their cargoes. Such ports may be either upon the immediate sea-coast, or at some distance from the mouth of a river. The former, again, may either possess a broad expanse of sheltered sea, or, as they are called, roads; or they may be placed upon unprotected open shores. Roads also may be natural or artificial, open or sheltered, according to the configuration of the coast, and of the bed of the sea in the particular direction under consideration. But of whatever description they may be, their utility mainly depends upon their possessing a sufficient depth of water for a vessel to ride at anchor at any time of the tides; whilst the bottom must be sufficiently firm to allow the anchors to hold in a storm. If such roads have convenient access, they facilitate commerce by

forming calling stations where vessels may wait for orders, or where they may wait for the winds or tides requisite to carry them into harbour.

Both roads and ports may be further subclassified into those without tides and those with tides, according as they may be situated upon waters affected or not by that semi-diurnal inequality. The ports upon the Mediterranean, the Gulf of Mexico, the Caspian, and the great fresh-water lakes, may be considered as of the former class; those upon the shores of the ocean as of the latter. Practically, also, the usages to which roads and ports are specially appropriated give rise to a further separation into the respective classes of commercial and military.

The variable degree in which harbours are affected by the tides produces a marked difference in the influence of roads upon their utility. For if the interior of the harbours should not possess a sufficient depth of water at low tides to allow vessels to enter, evidently it will be necessary that these should wait until a favourable moment should arrive, and this could only be effected in a road close to the mouth of the harbour. As the larger class of vessels are not constructed to take the ground, as it is called, or to lie high and dry between the intervals of the tides, it becomes necessary to construct floating docks to receive them in all ports so cir-cumstanced.

The utility of roads, whether open or sheltered, must of course depend upon the number of vessels they are able to accommodate. Sufficient space must be left round each vessel to allow of its swinging upon its anchor, according to the changes of the winds or the tides, without its being exposed to foul any other vessel. It is usual to calculate upon a radius of two cables' length for ships of war, and of about half that radius for merchant vessels.

On account of the great space thus required, roads cannot be entirely formed by artificial means; they must exist naturally, in a more or less perfect state. It is, however,

possible to improve such as may exist, by the construction of breakwaters or of jetties, so as to shelter any portion exposed to the violent action of storms; or by dredging any shoals to increase the available surface for anchorage. The roads of Plymouth, Cherbourg, Cette, and at the mouth of the Delaware in the United States, may be cited as illustrations of what has been done to create an artificial shelter; whilst the port of Nieuwe Diep, on the Zuiderzee, and of Lorient, may illustrate the methods employed to clear an already existing roadstead. There were, however, some peculiarities attached to the amelioration of the port of Nieuwe Diep which require to be noticed hereafter a little in detail.

The most advantageous situation for a port is at the extremity of a roadstead, especially if the channel of communication assumes a tortuous form. Should this not be the case, it will be necessary to construct piers, jetties, or moles, to destroy the undulations communicated by the open sea. It is also of vital importance for the security of a port that it should be surrounded by high lands on the in-shore, to guarantee vessels from the effects of the winds blowing from that direction.

As the piers at the mouths of harbours are constructed with a view to facilitate the manœuvres of vessels, it is found preferable to make greater provisions to assist their entry than their departure. A vessel in harbour can always wait for favourable weather; whilst those coming in from the open sea may often be driven in by stress of weather. In all tidal harbours, also, it is necessary to place the piers so that they may coincide with the direction of the currents, and in such a manner that the ships should not be carried against them whilst passing to the interior. Of course this precaution will require to be observed in tideless harbours, if any decidedly marked littoral current should exist; but it is of more serious importance where the currents flow in alternate directions than where they are permanent. It is to be observed, however, that the manner in which vessels are towed out from

the interior of a port will influence the form of the piers to a certain extent. Because if the vessels are towed in by men, or warped in by a rope, the piers must be carried out so far that they should be able to make their first tack without falling upon the opposite side; whilst if the vessels be towed out by steamers, the extension of the piers need only be regulated by the necessity for protecting the entry of the harbour from the effects of the currents.

Before constructing any pier or jetty, it is essential to study the movement of the alluvions upon the coast upon which they are to be placed. They frequently produce the effect before described as attached to other projections upon the shore; that is to say, they give rise to depositions of shingle or of sand, susceptible of diminishing the depth of water at the entrance, or even of accumulating silt in the harbour to such an extent as to close it entirely.

On the shores of the Mediterranean this tendency of jetties to produce the silting up of harbours is so strongly marked, and has been observed so long, that the ancient Romans adopted a peculiar construction with a view to obviate it. They built their moles, in fact, in a series of piers and arches, through the open spaces of which the sea passed, without losing its agitation or its littoral current. Vauban appears to have considered this mode of construction to have been the most advisable in similar positions, and of late years one of the most distinguished Neapolitan engineers, M. Fazio, has recalled the attention of the profession to the subject in a publication of singular merit, entitled " Discorse trè intorno al miglior Sistema di Costruzione de' Porti." Napoli, 1828. The system he recommended is represented in the accom. panying sketch; but it is far from being demonstrated that the results obtained upon the Neapolitan shore would be obtained in others. Open moles do, indeed, allow the littoral current to act partially; but the feeble portion which remains can only transport the alluvions when the sea is sufficiently
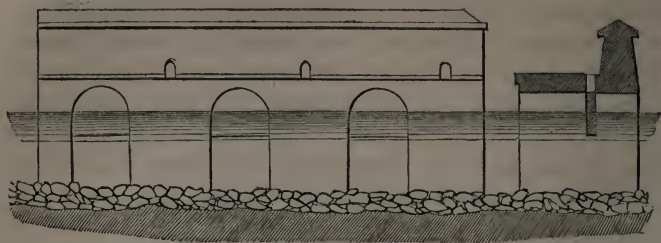
agitated to maintain them in suspension ; so that the agitation of the sea appears to be necessary to maintain the depth of water. It follows, therefore, that the more effectually the open moles shelter the interior of the harbour, the less likely are they to produce the desired object of preventing it from becoming silted up.

During the last century, and even in many cases at the present day, the means resorted to for obviating the gradual shoaling of harbours was to construct artificial backwaters with sluice gates. But, however powerful they may be, the results obtained by them are always unsatisfactory, because the sand or silt removed by them is invariably thrown down at a short distance from the point where the stream from the sluice has its velocity destroyed by that of the littoral current, at which point a bar will be formed, usually across the mouth of the harbour. The history of such ports as Dover, Folkestone, Newhaven, Fécamp, Brighton, Dieppe, Hâvre, and Ostend, demonstrates the inefficiency of all such means of combating the tendency to fill up indentations on the outline of a coast situated upon the line of advance of alluvions set in motion by a strong littoral tide. But at Nieuwe Diep the Dutch engineers, by combining the direction of their sluices so as to obtain at the same time the benefit of the scouring power of the tides, succeeded in forming and maintaining a new channel to a natural harbour through what previously was a very extensive sand-bank. In all these cases it is only

by directing the action of natural causes that success can be hoped for; the few artificial means at our disposal are power-less before the operations of nature.

In the French ports, so strongly does the conviction of the inutility of sluicing prevail, that the engineers have almost entirely abandoned it. Their efforts are now directed to ascertain the amount of shingle annually brought in, and to remove it by dredging in the most economical manner; taking care to deposit the silt in such positions as shall not allow of its being brought back into the harbour.
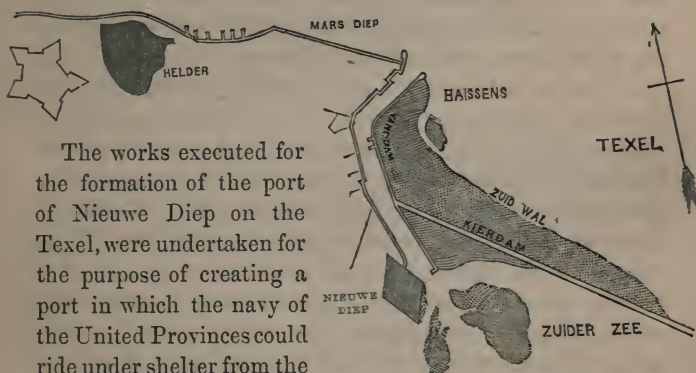
The works executed for the formation of the port of Nieuwe Diep on the Texel, were undertaken for the purpose of creating a port in which the navy of the United Provinces could ride under shelter from the storms and floating ice which render that part of the coast so dangerous in winter. A shallow pass existed between the land of North Holland and a sand-bank, called the Zuid Wal, which separated the Zuiderzee from the Texel, and converted the former into a secure roadstead; but the depth of water in the pass was only about from 12 to 13 feet deep at high water. The extent of the proposed operations rendered the use of the dredging machinery known at the epoch (1781) inap-plicable; the Chevalier Brunings therefore adopted the system of directing the flow of the tide-wave between a series of dykes, so as to concentrate its action upon those portions of the pass where it was desired to obtain the increased depth.

The Zuid Wal was originally about from 2 to 4 feet below
the level of high tides, and from 18 to 24 inches above low
water; the tides rise in front of the town of Helder about
5 feet 3 inches, and in the Nieuwe Diep about 4 feet 8 inches,
on the average. It was observed that whilst the bank was
under water the velocity of the current in the pass was slight,
but that it acquired much greater force about the ends of the
tides, especially at the ebbs. A larger quantity of water
was therefore made to follow the channel intended to be
deepened, by constructing a jetty, or vangdam, on the west
side of the sand-bank; it was entirely above water, and
nearly two miles long upon the bank itself, with an extension
to a point beyond the northern entrance of the military har-
bour of about two-thirds of a mile. Some perpendicular jetties
were also placed upon the dykes on the western side of the
port, to confine the scouring action of the current in that
direction. A submersible dyke was placed on the edge of the
Zuid Wal (a keerdam) which allowed the water to flow over
in either direction at certain periods of the tides. Those
portions of the bed of the pass which were not able to be
removed by the action of the current, were loosened by a
species of harrow, or dredged. The results produced by the
works were such that in the year 1794 the depth of water in
the pass was not less than from 26 to 33 feet, and in some
parts as much as 40 feet, at the low tides; and so judiciously
had they been executed that the total cost had not exceeded
150,000*l.* Subsequently the basin was constructed, and both
under the government of Napoleon and of the late King of
Holland, the town of Nieuwe Diep has continually increased
in importance.

Reverting to the considerations affecting the positions of
piers or jetties, they will be found to depend upon the
following general conditions :—the direction of the prevailing
winds, of the currents, and upon the progress of the alluvions,
the depth of the sea, the size intended to be given to the
port, and the character of vessels the latter is intended to

receive; together with the necessity for facilitating the entry or departure. The captains and pilots frequenting the port are the parties who are most likely to possess accurate information upon these points; but, in addition to this, it is indispensable to have soundings taken not only on the immediate site of the proposed jetty, but also to a considerable distance if any bar exist.

A jetty placed at an angle of 12° with the direction of the reigning wind, is usually found to afford the greatest facilities for the manœuvres of shipping. The length need hardly exceed the extreme low-water line, although unquestionably the entry would be safer if the jetty were carried further out. It is very rarely, however, that the advantage thus gained will compensate for the increased expense of executing the masonry under water.

If two jetties be required, it is advisable to make the one immediately under the prevailing wind longer than the other; but there are circumstances which may materially modify the application of this rule, or even reverse it entirely. Thus, the commercial port of Cherbourg has the windward jetty shorter than the leeward, for the following reasons:—the port is principally resorted to as a refuge in stormy weather, and as the storms upon this coast come principally from the west, they are more unfavourable for vessels standing *down* than for those standing *up* the Channel; because the latter can either run past, or make a port further east; whilst Cherbourg itself is the last port of refuge vessels standing down channel, on the south shore, can make. The port is therefore used principally by outward-bound vessels, and directly the wind shifts to the east all those in the harbour leave as rapidly as possible. It is customary to perform the hauling by men, and to carry the vessels out so far that they shall be able to run their first tack clear of the western jetty; the eastern, or leeward, jetty, therefore, has been carried out beyond it, in order that two or three vessels may leave at the same time.

Belidor was of opinion that if the line of direction of the jetties cut that of the littoral current, it was advisable to make the upper one shorter than the lower, because he conceived that the water striking the advanced portion would be reflected and produce a species of counter-current favourable to the entry of the port. But Minard justly observes that this object will be equally attained by the prolongation of the upper jetty, because the indraught of the port will create a back current. The length to be given to the jetties will therefore be decided by considerations independent of this particular one.

The disposition of jetties, in plan, is a point upon which great diversity of opinion exists amongst engineers. For some reasons it appears desirable to construct them on two curved parallel lines, until near the extremity, with the convex side turned towards the direction of the progress of the alluvions. In this case the scouring action of the water from the inner harbour, whether produced by sluices or simply by the tidal action, will be more effectual against the bar which usually forms at the head of the inner jetty, by the centrifugal force of the water deflected from the outer side. Moreover, this disposition is more favourable for the protection of the interior of the harbour from the effects of the wind,

But if the jetties be executed in smooth dressed masonry the transmission of the waves takes place with undiminished intensity. The Romans appear to have noticed this effect, for all the old ports of the Mediterranean have a polygonal form, and it has evidently been an object with their engineers to avoid joining the several straight lines by curves filling in the angles. On the other hand, it was noticed in the port of Hâvre that the waves were reflected from the opposite faces of the jetties, which were constructed of this polygonal form; and the manœuvres of the vessels were much impeded by the constant changes in the direction of the waves thus produced

A very sensible improvement in the tranquillity of the outer harbour has been produced by the construction of an open timber breakwater, backed by a shelving shore of masonry, upon which the waves, whether driven in directly, or merely reflected from the opposite jetty, lose a great portion of their power. A similar system had previously been tried at the entry of the port of Dieppe (see sketch in margin) where likewise it met with considerable success.

The width usually given to the channel between the jetties at the entrance of a harbour is that which shall be sufficient to allow the passage of three of the largest ships frequenting it, under sail, and at the same time. The minimum may vary between 100 and 240 feet, according to the size of the ships and to the power of the sluices. At the extremities the width should be increased; because the ships require more room to perform their evolutions whilst under the influence of the way they carry in from the open sea, than when they have followed the narrow channel for some time. The introduction of steam-tugs has called for a greater width of channel than was required under the old system.
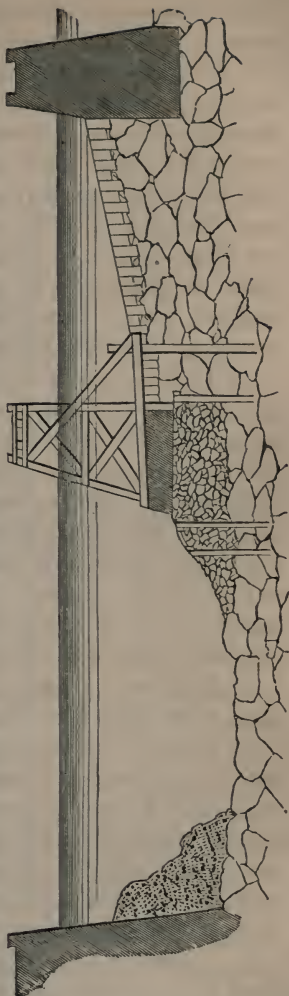
The roadway of the jetties should be finished off at a height sufficient to guarantee the men employed upon them from the effects of the sea in ordinary states of the weather. From 7 to 9 feet above high water spring tides will be sufficient; but the extremity, or the head, must be raised about 2 feet higher than the remaining portion. The heads, or extreme ends, may be erected with a width at the crown of from 27 to 36 or 40 feet; whilst the intermediate parts may vary from 7 to 20 feet, according to the materials employed. When the jetties are in wood, the smaller dimensions are employed; stone jetties are very rarely made less than 12 feet wide upon the line of the pavement.

The form to be given to the transverse section of a jetty is regulated by the nature of the materials employed in its construction, as much as by the dynamical effect of the waves. The materials may be either wood, loose rubble-stone, or solid masonry bedded in mortar.

Wooden jetties may be en-
tirely open, or filled in with
rubble either entirely or
partially; or occasionally they
are placed upon the crown of
a subsidiary jetty, finishing at
a point below the high-water
line, which is executed in
rubble masonry or loose
stones. The lower part of the majority of wooden jetties is, however, covered either by a mass of concrete, of loose stones, or of fascines, dressed with slopes both to the seaward and the inside of the harbour, forming a kind of ledge which serves to defend the foundations.
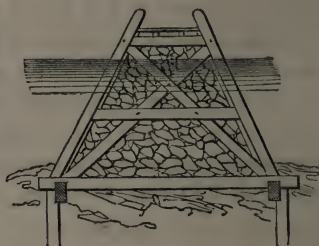
The frames of such jetties are placed at distances apart of from 6 to 10 feet, according to the depth of water and the habitual agitation of the position in which they are to be placed. They are made in the form of a trapezium, the inclined sides being respectively turned towards the chan-

nel and the open sea, and forming with the vertical line an
angle of from 13° to 33°. The timbers consist of two or
three posts, tied together by horizontal clipping pieces, with
raking struts or braces, forming with the horizontal ties
a system of triangles. Wales, cills, and heads tie these
separate frames together longitudinally. In the best works
of this description lately executed, all the joints are made by
halving and bolting, for it is found that the continual motion
of the waves causes the tenons to work in the mortices
wherever that style of joint is used, and that there is no
effectual way of remedying the loosening thus produced;
whilst, if the joints be halved and bolted, they may be
tightened up by screwing the bolts, should they have worn.
All the wood-work should be tarred, and precautions must be
taken to defend it from the attacks of the boring worms,
whose ravages will be noticed hereafter.

The upper sills carry joists, upon which is laid a planking,
usually from 4 to 5 inches thick, and with spaces of about
1 to $1\frac{1}{4}$ inch wide between each plank, to allow of the
escape of any water breaking over them. The planks are
spiked down to the joists, and a species of bridging or tying-
down joist is bolted upon their extremities to the sill resting
immediately upon the framework.

When the jetties are filled in with rubble-stone, the cases
to retain the latter are formed by close boards, laid horizon-
tally against the upright posts. The interior is filled in
sometimes with shingle, sand, or clay, as well as with stone,
and the recent application of Portland cement concrete in the
execution of such works appears likely to exercise impor-
tant effects upon this branch of construction. The best
position for the horizontal planking appears to be upon the
outside of the posts, because, although when it is placed upon
the inside it resists the thrust of the materials inclosed more
effectually, it will, on the contrary, when on the outside,
destroy the action of the waves upon the framing to a greater
extent. In the latter position also the planking can be more

easily repaired, and no asperities are offered able to affect or
be affected by any vessels which may rub against the jetties
in passing. It is a very important rule to be observed
in all constructions connected with piers or quays, that
no essential parts of the framing be exposed to the abrasion
of vessels either passing or stationary; wherever there is
a possibility of any occurrence of this description, it is advis-
able to place a firring to protect the permanent work.

In modern jetties the frames are made distinct from the
piles or other portions of the wood-work in or near the
ground. There is great difficulty, in fact, in driving with
regularity such long piles as would be able to receive the
flooring; and it is very easy to place the whole of one of the
previously-prepared frames of the upper structure upon its
foundations during the interval between two consecutive tides.
The supposed advantage to the solidity of the structure
in consequence of the posts being identical with the piles,
it may also be observed, soon ceases to exist; for in a short
time the destruction of the wood from the alternations of
dryness and wetness, or from the attacks of the worm,
render it necessary to replace portions of the work.

It has been observed that piles driven into the sea-shore
are rapidly laid bare by the shock of the waves. The
ground-swell acts upon the bed of the sea, and in time
produces a conical depression round the head of the pile,
whose depth may sometimes become as much as from 2 to
3 feet in a tide. These depressions extend on all sides,
so that the piles are often laid bare for a considerable length;
and to obviate this danger it is usual either to fill in between
the pile-heads with concrete or with stone rubble, or, in
Holland, to place a matting of fascines loaded with rubble,
through which the piles are subsequently driven.

The advantages offered by wooden jetties may be stated
to consist in the fact that they are rapidly and economically
constructed; the disadvantages they present consist in the
frequency and cost of their repairs, and also that they

do not effectually guarantee the interior of the harbour from littoral currents if totally or partially open, nor do they destroy the agitation of the waves. It is on this account that in many ports the system of partial filling has been resorted to, and the practice usually followed is, to carry up the filling to the level of high spring-tides in very exposed situations, or only to that of the high neap-tides in others.

Stone jetties are executed either with a hearting of rubble masonry or of concrete cased with ashlar, or with an embankment of earthwork cased by external walls tied together by cross walls, which form, in fact, so many separate compartments; or even occasionally of loose rubble. In the
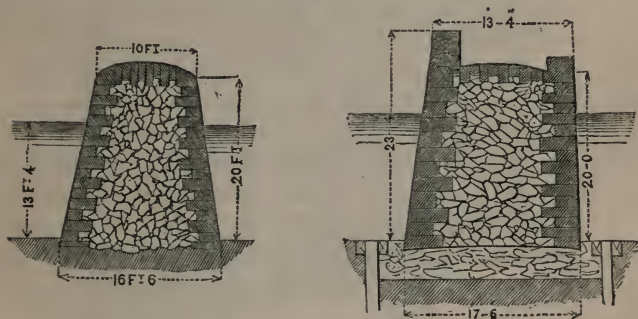
latter case, however, the inner face towards the passage of the harbour is executed in coursed masonry with a vertical or nearly vertical face, in order not to interfere more than is absolutely necessary with the water-way. Telford adopted innumerable varieties in the methods of bedding and bonding the masonry for these various descriptions of jetties, but there does not appear to exist any necessity for observing other rules in their construction than will be found enumerated hereafter.

In positions where it is easy to obtain large stones of a nature to resist the action of sea water, it is preferable to
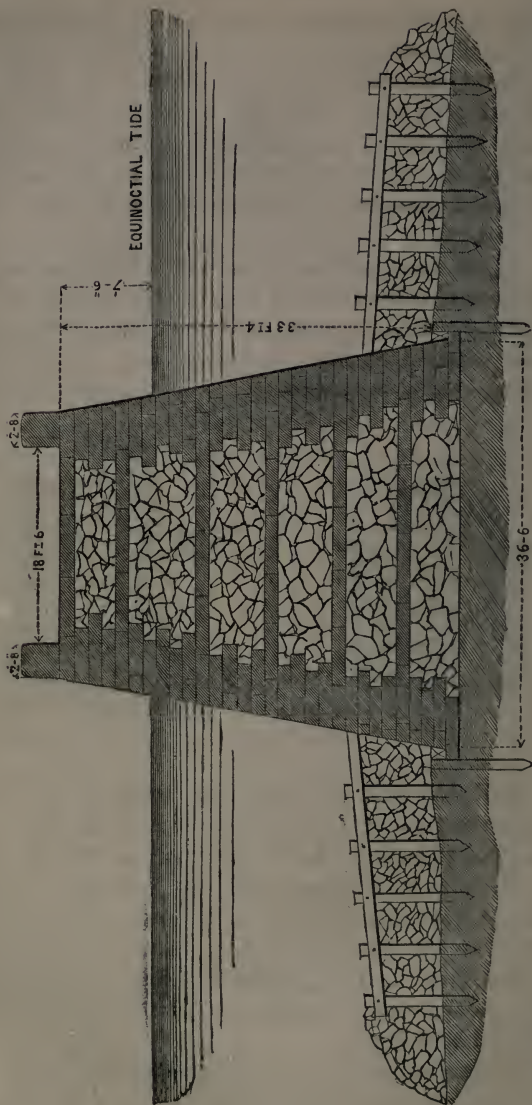
execute jetties with ashlar facings, and, generally speaking, to fill in between them with rubble masonry or concrete. A vertical face, we have already seen, destroys the violence of the waves with greater rapidity and more effectually than a long slope, such as every loose rubble jetty must assume, provided that it be constructed of a sufficient dimension; and with the requisite conditions of bonding together the several parts, a wall of such a profile will require less repair than a mere heap of small materials, each of which is susceptible of being displaced in a storm. The largest stones which can be obtained ought to be used, especially at the height corresponding with the greatest agitation of the waves, and for the upper courses: horizontal bonding courses should be introduced at regular intervals, with plugs or dowels connecting the several stones, and the upper surface of the filling in must be carefully paved so as to throw off any rain or sea-water falling upon it. The example given on the opposite page will illustrate the most theoretically perfect mode of executing such works; it is copied from the southern jetty of the port of Havre, which is exposed to very violent storms in winter, and in all times to a powerful littoral current.

When the interior of the jetty is filled with earthwork, it is necessary to place the counterforts tying the walls together at distances varying from 16 to 45 feet in the clear, making the counterforts from 6 to 10 feet wide. The thickness of the retaining wall must exceed that absolutely required, to ensure a resistance to the thrust of the embankment under ordinary circumstances, because the action of the waves changes very materially their conditions of stability. The most important precaution to be taken is to pave the top so as effectually to remove any water falling upon it. The inclination to be given to the walls may vary from 1 in 4 to 1 in 8; perhaps the latter is preferable as a general rule.

In some positions the progress of the shingle is found to exercise an important and very destructive effect upon the piers projecting within its line, in consequence of its friction

upon the stonework.   De Cessart recommended that a casing of planks from 3 to 4 inches thick be placed round the portions exposed to this abrasion, and that they should be nailed to horizontal whalings let into the stonework.
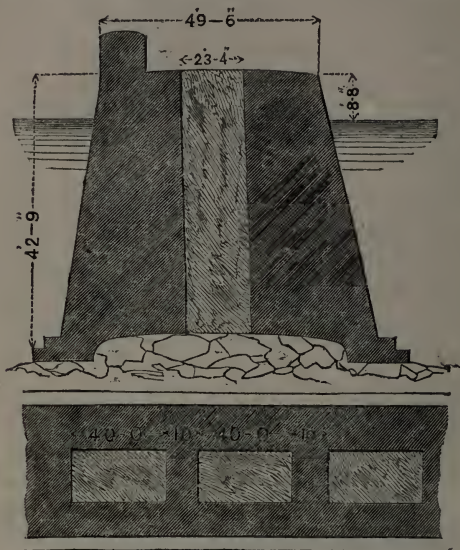
If the use of such boarding be objected to, it will be necessary to execute the portion thus rubbed by the shingle in granite, and under any circumstances to avoid the use of soft argillaceous or calcareous stones.

The foundations of jetties should be executed in the most substantial manner possible, and either upon a general bed of concrete, or upon a platform laid upon piles and surrounded by sheet piling; if the subsoil be of a nature easily removed by the repercussion of the waves or the action of the current, it may also be necessary to construct a wide apron, in a similar manner to the one executed at Havre, represented in the fig. at page 98.   These aprons are more peculiarly required at the head of the jetties, where the ground-swell

is the greatest; and they should be carried down as low as possible, the upper surface having either a slope or a curvature towards the open sea, so as to decompose the shock of any waves breaking on it.

If the extremity of the pier be carried out far into the sea, so that the foundations be below the lowest tides, it will be found almost impossible to execute them in a cofferdam. The modes hitherto employed under such circumstances have been to construct them of loose rubble-stone up to the low-water mark, as in the cases of the piers at Aberdeen erected by Telford, or of those at Honfleur; or to execute that portion with concrete, or with masonry sunk in caissons.

The loose rubble foundations answer in positions where there is no danger of the substrata on which they repose being removed, and when the passing current carries a sufficient quantity of mud or sand to fill up the interstices of the stones. Works of this description, if executed in tolerably deep water, assume the profile upon a line of direc-

tion of the prevailing wind, which may be thus described :— On the outside, and in the part situated below the usual action of the waves, the slope of the materials, as they
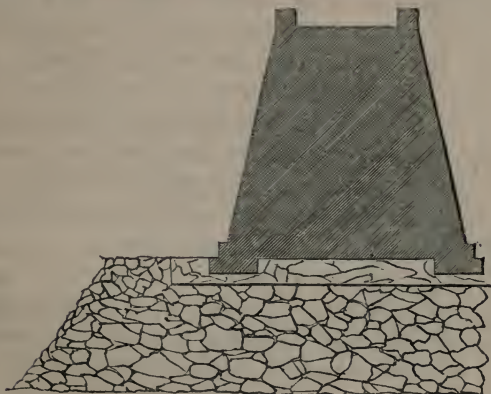
arrange themselves naturally, will be tolerably steep, and
about $1\frac{1}{2}$ to 2. In the zone exposed to the action of the
waves it becomes about 6 to 11; and the inner slope, which
is of course protected by the other, assumes the proportion of
1 to 2. The lower slope, or the one beneath the action of
the waves, is, however, the only one which has any fixity, so
to speak; and it is also to be observed, that in shallow water
the ground-swell appears to destroy it even in this portion,
and to give rise to constant changes in the outline. For
instance, a rubble jetty executed upon a ledge, called the
Boyard, in the roads of Aix, on the western shores of
France, was continually undermined at the foot, although the
foundations were placed at 14 feet below low-water line. It
is therefore necessary to cover the smaller stones, of which
the body of such jetties is composed, with blocks of con-
siderable dimensions at the feet, and also in the zones exposed
to the action of the waves. The immediate position of the
intended jetty should also be covered entirely by a bed of
concrete, executed after a sufficient time has been given to
allow the subsidence of the rubble to take its full effect, and
the masonry elevated upon this concrete. The sketch on the
preceding page, representing the jetty of Honfleur, at the
mouth of the Seine, will illustrate this construction.

When the foundations are executed in concrete, the exter-
nal edges should be protected by sheet piling, and precautions
must be taken to prevent their being undermined. The
surface of the place intended to receive the concrete must be
cleared of any alluvial mud or peat, and as far as possible
of any compressible substratum. But the most important
condition for ensuring the permanence of this description of
work is, that the lime or cement used be of a nature able
to resist the chemical effects of the sea-water.

Smeaton executed the foundations of the Ramsgate Har-
bour in caissons, sunk afterwards upon beds previously pre-
pared to receive them by means of the diving-bell. The
piers are carried out about 300 feet upon a chalky bottom, at

a depth varying from 8 to 10 feet below low-water mark of spring tides. The caissons were about 10 feet wide, and 34 feet long, measured perpendicularly to the axis of the pier. The heavy storms which blow upon this part of the coast from the S.E. moved the caissons, until they were weighted by the superincumbent masonry.

Jetties entirely in loose rubble work are principally constructed for the purpose of destroying the force of the waves, without its being intended to make them serve for the purpose of assisting the manœuvres of vessels entering or departing. Such a mode of construction may be advisable when the rough materials are easily procured, and when skilled labour is exorbitantly dear; but, as a general rule, it will be found that the ultimate expense of the maintenance of such works will more than counterbalance any economy in the original outlay. Telford has, however, executed several jetties in this manner, of which an illustration from the eastern arm of the Kingstown Harbour is selected. In other cases, as at Peterhead, he made the inner side with a vertical face of dressed masonry; but it is to be remarked, that the occasions on which that eminent engineer resorted to this mode of construction were decidedly exceptions from his usual course, and that wherever it was economically possible to execute jetties in coursed masonry he resorted to that system.
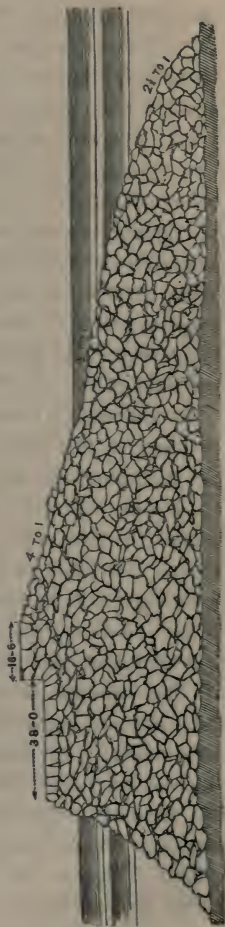
In addition to the interference with the translation of waves into the interior of harbours offered by the form and disposition of the jetties, or by the breakwaters before described, that object is sometimes effected by means of spurs projecting from the inner face of the jetties into the harbours. This is a system only to be resorted to upon extraordinary occasions; for, as the spurs project into the direct line of the channel, vessels entering the harbour must occasionally be forced to go through manœuvres attended with considerable danger. The practice of engineers, of late years, has certainly been to avoid any kind of deviation from the regularity of outline of harbours for this reason. The submersible jetties, formerly constructed in prolongation of the principal ones, or more frequently of the leeward jetties, have also been abandoned. Indeed it was found that, as they were covered at high tide, they became little else than sunken reefs in the course of vessels entering, and gave rise frequently to serious complications of the tides and currents of the port.

In the above remarks upon the construction of the jetties or piers at the entry of harbours, it has been assumed that the roadstead was sufficiently sheltered to allow the formation of a port, without the necessity for the execution of any works in the roads themselves. This, however, is not always the case, and, as was before said, the formation of a breakwater is sometimes necessary to secure the tranquillity of the roads. Plymouth, Cherbourg, Cette, and the port at the mouth of the Delaware, have been cited as illustrations of this species of construction, and they offer sufficient differences of *principle* even to require a somewhat detailed examination. A notice of the breakwater of the port of Buffalo, on Lake Erie, is added, for the purpose of showing the methods adopted by the American engineers in what may really be called their fresh-water seas.

The "Digue" of Cherbourg, the first in chronological order and in size, is unquestionably one of the boldest

and most gigantic works executed by man. Its total length is about 4120 yards, and it consists of two arms, respectively 2441 and 1679 yards long, forming at their junction an obtuse salient angle towards the open sea of about 169°, with an average depth of water, at high spring tides, of about 62 feet. The foundations for a circular battery, 100 feet in diameter, have been prepared at the east end, and at the west end, for a similar fort of 134 feet in diameter; whilst at the point of junction of the two arms, the foundations have been laid for a fort of about 640 feet in development. The width of the passes between the extremities of the digue and the main land, at the points where fortifications (crossing their fires with those of the intended forts on the digue) are erected, is respectively 1040 and 2515 yards. The area sheltered by this work is about equal to 1927 English acres at low tides; but of this, not more than 696 acres have a depth of 27 feet at the lowest tides. Of this deep-water surface it also appears that nearly two-thirds are exposed to the unbroken violence of the ocean during the winter months, so that really the roads of Cherbourg, notwithstanding the immense cost of the digue, can hardly be said to be able to shelter more than from 25 to 30 sail of the line, inasmuch as each vessel requires from about $8\frac{1}{2}$ to 10 acres superficial to swing freely upon its anchors. In the shallower parts of the roads, an equal number of frigates could be made to ride in safety.

The original intention in constructing the digue was, that it should be submersible at one-third of the rising tide. This intention was subsequently abandoned, and the height was proposed to be at different periods, firstly, that of the ordinary spring tides, then 10 feet above that line, and finally the actual height of 12 feet 6 inches was adopted. The sketch No. 1 overleaf will represent the normal section of the digue; the sketches Nos. 2, 3, and 4, are introduced to show the modifications of the profile superinduced by the

action of the sea between the years 1788 and 1829. As will be seen upon inspection of these figures, the slope

No. 1.

No. 2.
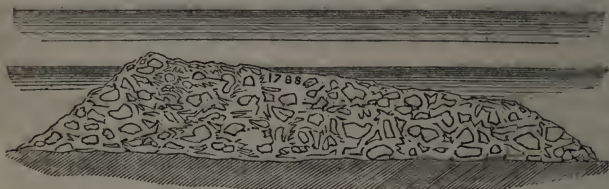
No. 3.
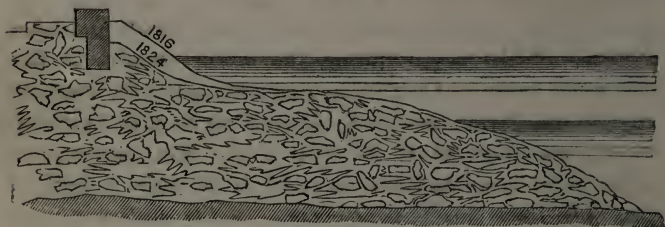
No. 4.

of the seaward face had materially changed; and in 1829, as it was found that the tranquillity of the roads was by

no means secured, and that the small blocks were constantly swept over from the sea side to the inner face, it was resolved, after long and anxious deliberation, to crown the top of the sea slope with a vertical wall, as shown. The original digue was completed to the line of the low spring tides in small blocks, and after the materials thus added had been allowed to settle, they were covered with a bed of hydraulic concrete 5 feet thick, and upon this a solid wall of coursed ashlar masonry, the external and internal faces of which were executed in granite, with rubble hearting, was erected as shown. The top of the sea slope is covered with large loose blocks, and at the extremities of the wings it is further protected by immense artificial blocks, of about 40 tons weight each, formed of rubble set in Roman or Portland cement.

In Baron Cachin's history of this astounding work, and in Reibel's edition of Sganzin, may be found further details of the mode of construction, and of the accidents which happened to the digue, from the year 1786, when De Cessart tried his ingenious but unsuccessful system of sinking vast cones of masonry, up to the year 1840. Since that period the construction of the upright wall has been continued, without being interrupted by any accident which should lead to a modification of the system. Some serious settlements have taken place, from the unequal compression of the new rubble work under the enormous pressure of the upper wall; and possibly also the older portions of the digue may have been similarly disturbed. At any rate, the whole mass of the looser ubble has been considerably compressed, for the wall has been observed to sink throughout its length about 2 feet on the average, the movement taking place with considerable rapidity the first year, and diminishing gradually during the second and third, whilst it is barely perceptible in the fourth. This result ought not, however, to excite surprise, for the stones used in the body of the rubble work occupy so greatly increased a volume beyond their natural

one whilst in the quarry, that their bulk in the digue before
compression is to that they previously occupied as 1·5 to 1.
The result of the compression has been to produce in the
north and south faces of the vertical wall a series of irregu-
larities and curved lines, both in a horizontal and a vertical
direction.   The maximum deviation of the former is said to
have a chord of about 730 feet, with a versed sine of 17 inches ;
of the latter, the chord is about 2000 feet, and the versed
sine 24 inches ; and in some instances the cracks superin-
duced in the masonry extended to such a degree as to require
the demolition of parts of the wall, together with modifica-
tions of the heights of the next following courses, in order
to secure horizontality in the beds.   As the parts which have
been subject to these settlements have now for several years
resisted the effects of the heaviest storms, they may perhaps
be considered not to endanger the solidity of the work ; and at
all events they must be regarded as inevitably attached to the
mode of construction of the body of the digue, viz., of loose
stone rubble left to arrange itself.

The breakwater of Plymouth is formed in a bay sheltered
on three sides by land rising to a considerable height, and
only open to the south.   Several banks, or natural reefs of
rocks, exist, between which and the shore there were three
principal passes towards the east, the west, and in the center.
The breakwater is erected upon the banks situated the
nearest to the interior of the harbour, and closes the center
passage ; the banks situated more towards the open sea
serve to break the fury of the waves before they arrive
upon the breakwater.

The main body of the breakwater is placed perpendicu-
larly to the S.S.E., from which quarter the severest storms
assail the Plymouth Roads.   The total length is 1700 yards,
of which the rectilineal central part occupies 1000 yards,
and the two arms, forming on either side angles of about
135° with the center, occupy respectively 350 yards each.

A surface of about 1120 acres is, by means of this work, rendered available for large vessels.

Originally it was intended to make the width of the top of the breakwater only 11 yards, and that of the bottom about 55 yards; but during the execution of the works, the width of the top has been increased to 15 yards, and that of the bottom to 133 yards. At the level of the low water at spring tides, a set-off 22 yards in width is formed, and the slopes from this point upwards, on the sea side, are paved with large stones, 4 feet by 3 feet 6 inches, by about 3 feet thick, laid with an inclination of 5 base to 1 height and bedded in Roman cement; and it is proposed to continue this paving below the lowest water line by means of the diving-bell. The height of the crown of the breakwater is only 2 feet above the level of high spring tides.

It appears to be beyond question that the long slope of the Plymouth Breakwater is less exposed to be injured by the violent shocks of the sea than the vertical wall of the Cherbourg Digue; but at the same time it is equally beyond question, that the latter destroys far more effectually the agitation and undulation of the open sea, and offers a greater resistance to their transmission into the inner harbour, because the waves in Plymouth Sound during violent storms break over the slopes, whilst at Cherbourg all their effect is destroyed by the wall. In the latter case, however, the descending motion of the return wave is materially interfered with. The vertical wall at the top of the long slope transforms it, in fact, into a horizontal motion, whose velocity is highly dangerous to the stability of the foundation of the wall. It is also found that the large blocks of stone detached from the outer slopes are driven against the outer face of the wall with extraordinary violence during great storms, whilst upon the long paved face of the Plymouth Breakwater the waves, not meeting with any abrupt resistance, break in precisely the same manner upon the incline that they would do upon a natural shore, and with a considerably diminished degree of

violence. It is true that, in consequence of this form, they
acquire an increased horizontal velocity in their original
direction; but as the top of the slope is rendered as smooth
as possible, there are no salient points in the masonry able to
attract, as it were, the destructive action of the waves. Not-
withstanding the precautions observed in the execution of
the top slope of the breakwater, it is by no means of rare
occurrence that blocks weighing from 2 to 5 tons are carried
over from the sea to the land side; and in February, 1848,
considerable damage was caused to the upper parts.

A lighthouse is proposed to be erected at each extremity
of the breakwater; but only one has been completed.

The breakwater in Delaware Bay was designed not only to
form an artificial roadstead sheltered from the effects of the
prevailing winds, but also from the drift ice brought down
occasionally in large quantities from the upper parts of the
Schuylkill and Delaware Rivers. It was also contemplated
that the port thus created would rather be a place of refuge
for ships bound coastwise, than it would become a touching
port for vessels dropping down the river. In consequence of
these local circumstances, the works for the shelter of the
roads consist of a breakwater and what may be called an
ice-break. The breakwater itself is in a straight line, in a
direction W.N.W. to E.S.E., and of a total length of
1000 yards measured upon the line of high water, leaving a
channel of about 1000 yards in width between its E.S.E.
extremity and the main land. At a distance of 555 yards
from the W.N.W. extremity, the prolongation of the line of
the inner slope of the breakwater meets the line of the inner
slope of the ice-break, forming with it an angle, towards the
shore, of 146° 15′. From the point of intersection, the line
of the ice-break is carried respectively 272 yards W. by S.,
and 228 yards E. by N., making a total length of about
500 yards, with a clear passage of 350 yards between it and
the main breakwater.

The space thus sheltered has an area of about ⅕th of a mile so

far as the waves raised by winds from the N.W to the E., passing by the N., are concerned; and a space of $\frac{7}{25}$ths of a square mile so far as those caused by winds from the N.W. to the E. (by the N.) are concerned; and in both cases the minimum depth so sheltered is 24 feet. The area of sheltered road, with a minimum depth of 18 feet, is about $\frac{7}{10}$ths of a square mile. The tides in this locality are but feeble, for the average range of the neap tides is about 4 feet 8 inches, and that of the equinoctial spring tides about 7 feet 6 inches; whilst the greatest range that has been noticed has never exceeded 8 feet 10 inches vertical.

The transverse section of the breakwater was made as follows:—The inner slope, towards the harbour, was formed at an angle of 45° with the horizon; the top was made 30 feet
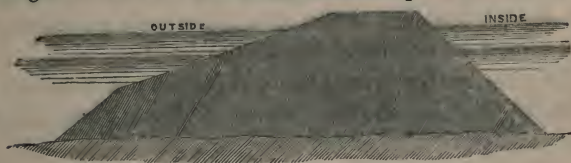
wide, and at 5 feet 4 inches above the level of the highest spring tides. The outer slope was carried down, with an inclination of 3 base to 1 in height, to a depth of about 19 feet from the highest spring tides, and from thence to the bottom, at an angle of 45°. The mass of the work between the sea bottom and a horizontal plane passing at 6 feet below the lowest spring tides, was formed of stones weighing from $\frac{1}{4}$ to 2 tons, and the slopes covered with blocks of from 2 to 3 tons minimum weight. Between this point and the plane corresponding with the lowest spring tides, the body of the work was executed in stones weighing from $\frac{1}{2}$ to $2\frac{1}{2}$ tons, protected externally by blocks weighing 3 tons each at least; and the upper portion was formed exclusively of blocks weighing from 4 to 5 tons, laid as regularly as possible, the slopes being covered with the largest blocks, laid as headers.

The breakwater of Cette is principally remarkable on

account of the great height to which it is carried above the highest water line; this is not less than 19 feet. A section of its normal profile has already been given at page 52: the total length is about 514 yards, and the outline on plan is convex towards the open sea. During its execution, observations were made from which it may be inferred that the constant undermining of the sand upon which this breakwater was constructed, so long, at least, as the transverse profile was made very steep towards the open sea, would indicate a danger of superinducing a ground-swell highly injurious to the permanent solidity of the works, unless the sea slope, in similar cases, were carried out at once to the full width. It is also seriously questioned by the pilots resorting to this harbour, whether the breakwater does not materially assist the natural tendency to silt up which so strongly marks this and several other ports of the Mediterranean.

The breakwater upon Lake Erie, at the entrance of the port of Buffalo, in the State of New York, is con-

structed with nearly as much solidity as similar works upon the shores of the ocean. Its length is 484 yards in a straight line; the platform at the level of the first set-off is 18 feet wide, and 5 feet above the water-line in the interior. A wall 5 feet high is carried up above this platform, and beyond this a gentle slope of about 3 base to 1 in height is carried down to the bottom of the lake. Towards the port the face of the breakwater is perpendicular, and it is defended from being injured by vessels lying alongside it by guard-piles driven in every 5 feet apart. A row of sheeting piles is driven upon the external edge to protect it from the effects of the ground-

swell; the mass of the breakwater is executed in loose rubble masonry.
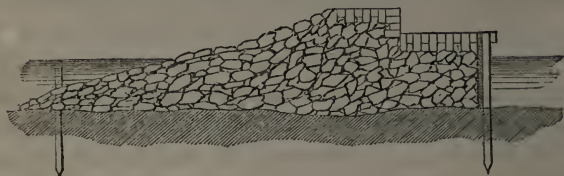
In addition to what has already been said with respect to the precautions requisite to be observed in the construction of piers and breakwaters, it is important that the lower courses of the masonry be covered by the succeeding courses as rapidly as possible, not only to enable them to resist the direct action of the waves, but also the syphonic action of the water driven into the joints. For the latter reason also it is important that the joints between the stones be executed with the most energetic cements, and be made to fit very closely. If the hearting be executed with small stones, the inequality between its rate and degree of compression is likely to give rise to hollow chambers, which facilitate this syphonic action; and it appears therefore indispensable to introduce a greater or less number of horizontal bond courses, according to the nature of the materials employed.

Experience also appears to show that it is safer to raise the masonry, in such positions, to its full height partially at once, rather than to endeavour to carry it up regularly throughout the whole length, in order that the superincumbent weight of the upper courses may assist in maintaining the lower ones in their places. This precaution is peculiarly necessary when the walls have reached the mean level of the sea, at which point the waves act with the greatest effect. In solid masonry in these positions, the rapid setting of the cements or mortars is a condition of vital importance; and it is also necessary that only such materials of either of these classes be employed, as allow of being prepared for use with salt or fresh water indifferently.

Beyond the jetties, in all seaports of importance, it is usual to construct an outer harbour, surrounded by quays, at the bottom of which are placed the docks intended to receive vessels of large tonnage, and to retain the water entering at high tide, so as to allow the operation of unloading to be performed whilst the vessels are afloat. Small vessels and fish-

ing craft generally remain in the outer harbour, as do also the coasters or other craft able to depart at half tide.   The sluice-gates, and the leading channels from the back-water, whether it be natural or artificial, are also placed upon some portion of the outer harbour.

The length to be given to this part of a port will depend very much upon the facilities it may possess, with respect to the entrance or departure of vessels.   It frequently happens that during windy weather these may retain a very consider-able portion of the momentum derived from the velocity they had whilst under sail; sufficient space must therefore be allowed for the destruction of this momentum before the vessels arrive at the locks giving access to the inner harbour. On this account, also, it is preferable to direct the entrance between the jetties a little out of the line of the prevailing winds, and to place the lock-gates somewhat out of the direct path followed by the vessels entering.   Generally speaking, it will be found sufficient to make the length of the outer harbour about 700 yards.

The quay walls of a harbour are required to fulfil the same conditions as the walls of river wharfs, that is to say, to resist the lateral thrust of the ground, and to facilitate the discharge of vessels.   For the attainment of the latter condition, it is important that they be as nearly vertical as possible; but in proportion as this object is attained, the stability of the wall itself is diminished.   The late Mr. Rennie, and after him the majority of English engineers, endeavoured to reconcile the two conditions by building their quay walls with a curvilinear batter on both sides, laying the courses normally to the curve. By this means the stability of the wall for the same cubical quantity of masonry is certainly increased, and the face stones —being, in fact, voussoirs—connect the masonry intimately throughout.   At the same time the mechanical difficulty of execution is greater than in a wall with horizontal masonry, and this mode of construction entails the necessity of using inclined piles, which should be avoided as much as

possible. The Dutch engineers occasionally incline the two
faces of the wall in a direction parallel one to the other, and
so that they overhang on the inner side at the top. The
radiating joints in such cases are dispensed with; but the
stability of such walls, especially when constructed upon soft
mud, is never satisfactory, for the overhanging portion of the
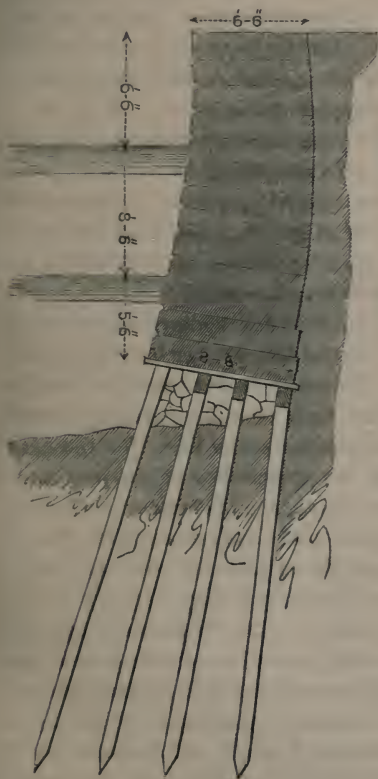
Fig. 1.   *Fig.* 2.

masonry adds to the
lateral thrust of the
earth upon that portion
of the foundations and
wall below the center
of gravity. Walls of
this description may
almost always be
noticed to have yielded
at the feet. In the
French ports upon the
Channel it is customary
to build the walls nearly
vertical in the manner
represented in fig. 2.,
which is taken from
the quay wall of the outer harbour at Havre. The mean
thickness adopted in these ports is not less than 0·40 of the

total height considered as unity, and, strange as it may appear
to our ideas upon the subject, it is found practically that this
great thickness is not sufficient to ensure the stability of the
walls in many cases, for many of them have yielded.

The rounded outline of the bottom of ships admits of the
formation of a set-off, or of an apron, to protect the founda-
tions.   In the case of the docks at Antwerp, as the rock in
which they were excavated was sufficiently solid to dispense
with the necessity of a facing of masonry, the set-off was
formed in the rock itself.   This is, however, a course of pro-
ceeding which should only be resorted to when there can be
no danger of the undermining of the walls.

The thickness to be given to the quay walls, and the pre-
cise mode of construction to be adopted, must evidently, from
what has been said above, depend upon local considerations
of the cost of materials and of labour.   The most important
theoretical consideration affecting them is to be found in the
fact that the earth behind them is exposed to be alternately
wet and dry twice a day, and that the capillary action of the
ground causes this action to rise to a greater height than the
limits of the tidal range.   The earth in this condition must be
considered to be a semifluid mass assuming naturally a slope
forming an acute angle with the horizontal line.   But the most
serious difficulty attending the construction of the quay walls
of ports arises from the yielding of the mud under the founda-
tions.   If the mud lie upon a solid substratum which can be
reached by piles, it is possible to found the wall in such a
manner as to guarantee it from any danger arising exclu-
sively from the vertical pressure.   But it frequently happens
that the mud moves laterally under the compression of the
earthwork behind the walls, driving out their foundations, and
forcing up the bed of the harbour.   Accidents of this descrip-
tion occurred at Southampton, Lorient, and Rochefort; and
it appears that if the stratum of mud be of great thickness,
the only effectual mode of combating the danger is to lighten
the vertical pressure of the filling behind the walls by means

of fascines, timber platforms, or by hollow vaulting. The quay at Lorient is erected upon a bed of mud of unfathomable depth, and in this case both the wall and the platform behind it are carried upon piles driven with the broad end downwards.

Guard piles ought to be placed in front of quay walls to protect them from the abrasion of the vessels moored alongside as they rise and fall with the tide, or from the shocks of vessels driven against the walls, occasionally with considerable violence. These piles need not descend below low-water mark of neap tides: they are usually bolted to the masonry, and covered with an iron cap. In the angles of harbours, staircases or inclined roads may be placed, to assist in unloading small boats. The only important precautions to be observed in their formation are, that all external arrises be rounded off, and every description of projection likely to injure the bottoms of vessels studiously avoided. The same remarks apply to all ladders mooring rings, or other facilities for the manœuvres of the port.

The dimensions and dispositions of the inner harbour will be regulated by the nature of the vessels frequenting it, and the depth must be such as at all times to exceed the draught of water of the largest vessel it is likely to receive. This excess of depth is required, firstly, to compensate for any loss of water which may take place between two consecutive tides, whether it arise from evaporation or leakage; secondly, to allow of the abstraction of a certain quantity of water for the purpose of scouring the passage in front of the lock-gates; thirdly, to prevent the possibility of the vessels grounding, should any agitation either be transmitted from the outer harbour, or be produced in any manner in the inner one; fourthly, to allow of the gates being opened a little before the period of the highest tide so as to permit vessels of light draught to leave at an early period; and fifthly, to provide against the gradual silting up of the inner harbour. In order to provide against all these sources of possible annoyance, and to secure

the eventual advantages, it is usual to make the depth of inner harbours from 2 to 3 feet in excess of what is absolutely required to receive the vessels frequenting it.

As an economical question, we may consider that the dimensions of length and breadth should be decided upon the principle that the greatest number of vessels should be able to lie alongside the quays, with the smallest amount of expense in the excavation of the water surface. At the same time, it is necessary to leave between the different tiers of vessels a space sufficient for the evolutions of those about to enter or depart. In some of the most convenient modern ports, intended to received commercial vessels only, the length is made about five times the width, and in these instances vessels often lie in three tiers on either side. In military ports, however, it is necessary to bring every vessel close to the quay, and therefore the proportionate length may be less than that above stated. At Cherbourg, where the expense of excavating the basins in the solid rock was enormous, their dimensions were reduced to the minimum; one of them was therefore made nearly square, or 754 feet wide by 852 feet long; whilst the second was made 656 feet wide by 1312 feet long, or in the proportion of 1 in width to 2 in length.

The gates closing the inner harbour should be constructed with a view to secure the most rapid operations in opening and shutting, and to render the leakage at the several joints as small as possible. Their width must be regulated by the class of vessels entering. Barques and sailing vessels under 500 tons burthen do not require a greater width than 50 feet; a first-class frigate does not require more than 52 feet; nor does a first-class sail of the line require more than 60 feet. But the colossal dimensions of some of the modern steamers renders it necessary to make the gates through which they are to pass not less than from 70 to 80 feet wide. It is customary to place sluices at the bottom of the lock-gates to assist in scouring the platform at the entry.

The depth of the floor of the passage will be regulated by

the draught of water of the vessels entering. A 500-ton vessel will draw about 16 feet, a first-class frigate about 22 feet, and a first-class man of war about 27 feet, supposing them to be under full load. As the draught of steam-boats is in nowise commensurate with their width, they may be considered to be comprised within these dimensions.

Unless there be very great inequalities of tide, one set of gates will be sufficient to retain the water during the period of the ebb; but it frequently happens that it is indispensable to place a set of gates to exclude the flood-tide, especially when repairs are likely to be required to the flooring of the gate passage, or the inner harbour. It appears, therefore, a very necessary precaution, to construct the chamber and passage so as to admit of placing two pairs of gates, respectively to provide against the ebb and the flood tides; and in many commercial ports it may even be advisable to place a second pair of ebb gates in order to allow the intermediate space to become a species of lock to facilitate the departure of small craft at the half tides. A provision should also be made for the insertion of a coffer-dam; and in almost all cases it will be necessary to construct a turning bridge for the purpose of connecting the roads or quays on either side of the passage. In the side walls of the lock chambers it is also customary to construct culverts, provided with gates and raising machinery, for the purpose of assisting the scouring action of the sluices in the gates themselves upon the passage leading up to the latter. It follows, therefore, from the necessity for these several works, that the length to be given to the entrance from the outer to the inner harbours of any port must vary according to the local conditions of tide, or of the communications between the two banks of the innner harbour.

Although, as was previously observed, the effect of sluices is in many cases merely to transpose the deposits of shingle or sand from the points directly within their influence to others where, perhaps, they may be somewhat less injurious,

yet it is possible to obtain by their means such remarkable
advantages, that it is necessary to dwell shortly upon their
consideration, especially as the real value of this class of
works is but little understood. The best form to be given
to an artificial backwater retained for this purpose would be a
sector of a circle, but with a chord line, towards the outlet,
formed by a portion of the
development of a circle of
greater radius than that of the
inner contour; the gates being
placed as nearly as possible in
the line of the centers. The
degree of efficiency of their action depends upon the
volume of water they can contain, and the velocity with which
this may be allowed to escape without injuring the foundations
of the jetties or other works it may encounter. So long as
the stream escaping from them is confined in such a manner
as to act entirely upon the channel, it is possible to obtain an
increase of depth, which in the immediate neighbourhood
of the sluice may attain as much as 8 feet. In proportion,
however, as the stream escaping loses its velocity, its power
of transporting the materials previously detached becomes
diminished ; so that it is by no means rare to observe that
the shingle or silt removed near the sluice is again deposited
nearer the mouth of the harbour; and in almost every instance
the meeting of the scouring stream with the littoral current,
should any such exist, gives rise to a bank at a distance from
the extremity of the surface guiding the water from the sluice,
depending upon the velocities of the latter and of the littoral
current. It is therefore of vital importance that the velocity
of the water at the moment of its leaving the sluices be as
great as possible ; that its path should be free from any ob-
structions likely to retard its flow; and that the distance of
the sluices from the head of the piers be such as to allow the
water leaving them to retain its velocity for some time after

it falls into the sea. It is also necessary that the direction of the outflowing stream correspond with that of the shingle or silt brought in by the returning tides.

Upon the various ports of the British Channel, especially upon those of the French, Belgian, and Dutch shores, many works of this description have been executed; and it appears from an examination of the results there obtained, that a velocity of about 5 feet 6 inches per second, immediately beyond the eddy produced near the sluices, is desirable in such cases as those in which the bottom of the harbour consists of small shingle. The distance of the most efficacious of these sluices from the extremities of the jetties does not exceed 900 yards; although, when the materials brought in by the tide consist of a sandy mud, there does not appear to be any serious inconvenience in making this distance 1000 yards. The cubical capacity of the sluice must be sufficient to ensure the flow of the sluicing stream for a period rather in excess of that required to remove the materials brought into the harbour during the intervals of the tides. It may be obtained either by retaining the water flowing in from the sea itself, or by upholding the land waters for periods sufficiently long to secure the quantity required, or by a combination of these sources.

In practice, the openings of the sluice gates vary from 7 to 20 feet in width, and the intermediate piers are made from 10 to 11 feet in width. Large gates are advantageous in this respect, that they interfere less with the discharge of the water than smaller ones would do; but at the same time their execution is more costly, they are more likely to get out of repair, and their maintenance, and also their ordinary working, is more difficult. The most important consideration affecting their construction is, however, more especially connected with the floor which must not only be capable of resisting the transporting power of the escaping water, but also of resisting the hydrostatical pressure of that which is retained in the inner basin. In many instances it has been deemed advisable

to make the total length of the floor not less than 120 feet, in order to obviate any danger of these causes affecting the stability of the sluices.

But it must always be borne in mind, whilst considering the expediency of these additions to the efficient working of harbours, that their first cost is usually very great, and their maintenance very expensive, whilst at the same time the effects they produce are only of a questionable character. Should the materials brought into a port be of a sandy or silty nature, it will almost always be found more economical to remove them by dredging; and, in many cases, the same remark will hold good with gravel or shingle. But, if a tidal current can be made to pass with considerable velocity along the passage leading to the inner harbour, or if, in fact, any natural back-water exist which can be directed so as to act efficiently for sluicing, without entailing any serious outlay, it is highly desirable that it should be made use of. Local circumstances must eventually decide this, as they must all other questions of detail.

A very important branch of the science of hydraulic engineering, as applied to the construction of sea works, is that connected with the chemical action of the salt water upon materials immersed in it, and the peculiar ravages some of these are exposed to from members of the animal kingdom.

Some stones and mortars, not only when immersed, but also when exposed to the sea air, may often be noticed to decompose and to become covered by an efflorescence of the carbonate of soda, resulting from the action of the hydro-chloride of soda in suspension in the atmosphere, or in combination with the water, upon the carbonate of lime. The hydrochlorides of magnesia present in sea-water act in a very peculiar manner upon some stones and mortars; for when the former exist in the state of protocarbonates of lime, the magnesia enters into combination with it, and as during that process a new crystalline arrangement takes place, it

is frequently the case that the stone disintegrates. With the argillo-calcareous stones, however, this action does not take place, and it would thus appear that the combination of the lime with the alumina is sufficiently energetic to enable the stones in which that state prevails to resist the decomposition of the sea-water. The same remarks apply to mortars and cements; for it is found that unless the mortars made with ordinary limes are perfectly carbonized before being immersed, or unless the cements be obtained from natural argillo-calcareous rocks, or, if artificial, unless the lime and alumina have been made to combine intimately by the effects of fusion, however well they may appear to resist in the commencement, they will eventually be certain to disintegrate. At Algiers, Brest, Cherbourg, and the Ile de Rhé, some mortars were employed for the formation of large blocks of concrete, and were composed of moderately hydraulic limes mixed with artificial puozzalanos, prepared, in accordance with Vicat's suggestion, merely by exposing clays to a low heat in such a manner as to allow free access of air to all the parts in incandescence. The concretes thus made resisted satisfactorily for some time, but at the expiration of two or three years they fell to powder; whilst in all cases where the natural puozzalanos have been employed they have not yielded. It appears, therefore, that there are certain changes produced in the alumina by the action of intense heat which render it more capable of combining with lime; and it is probably in this manner that we may account for the admirable results obtained by the application of the Portland cement.

Particular stones, however hard and polished they may be, and in spite of the incessant action of the waves, become rapidly and almost entirely covered with shells and sea-weed, in certain positions, whilst in others they are left bare. This also is true with respect to some mortars; for blocks of concrete, which have only been immersed for ten days, have been noticed to be covered with marine plants. The boring mol-

lusca frequently attack the softer limestones, with sufficient
rapidity to render it necessary to exercise great caution in the
choice of the materials employed within the range of their
destructive energies.   Granites and silicious sandstones are
free from their attacks, and some descriptions of limestones
enjoy the same immunities; but the precise nature of the
latter class of stones is not known with any tolerable degree
of certainty.   The animals exercising this action upon stones
are of the tribe of the *Lithodomi*, or more frequently, in
our seas, of the *Saxicava rugosa* and the *Pholas*, the latter
attacking principally the chalk, or other pure and soft car-
bonates of lime.

Iron, whether in the water, or only exposed to its vapours,
corrodes with great rapidity; wrought iron decaying, as
might be expected, more rapidly than the cast metal.
Painting or galvanizing does not appear to retard the de-
structive chemical action of the salt water materially, in
whatever state the iron may be; but there would appear to
be a specific difference in the nature of the action upon the
cast from that upon the wrought iron, for it is found that the
latter becomes simply oxidated to a greater or less depth,
whilst the former, after an immersion for about 30 years,
becomes converted so thoroughly into a carburet of iron,
closely resembling the plumbago of commerce, that it may be
easily cut with a knife.   De Cessart mentions that, in re-
moving some works executed by Vauban a century previously,
he found that in many instances the wrought-iron bolts were
intact, whilst other bolts, inserted in precisely analogous
positions at a subsequent period, had corroded within a very
few years.   There would, therefore, appear to be some
peculiar states of the iron as employed in the arts which
modify its powers of resistance to the chemical action of the
salt water.   The greatest practical inconveniences attached to
the chemical action of the sea-water upon iron are, firstly,
that its powers of resistance are diminished; and, secondly,
that as its bulk diminishes also, especially when oxidation

takes place, the play thus superinduced upon the framing it is intended to strengthen becomes very great.

Copper and gun-metal oxidate in salt water to a very insignificant depth; but they do not appear to be otherwise affected, nor do they lose their powers of resistance. If, by means of any description of paint, or of other preservatives, the oxidation of the exposed surfaces be prevented, these metals are frequently found to be covered with shells or marine plants.

The most important observation to be made with respect to the employment of metals in sea-water is, that under no circumstances should any two different kinds be employed in contact with one another. In such cases a galvanic action takes place by the intervention of the salt water, which produces very rapid and important chemical decomposition.

If wood be kept constantly under water it is found that it will last for an indefinite period, and that in the parts left alternately wet and dry, a collection of marine plants and shells, especially muscles, is rapidly formed. The principal danger to which wood is exposed in our seas is, however, that caused by the ravages of a species of worm called the *Teredo navalis*. It is said that this worm is a native of India, and that it was introduced to Holland some 200 years since, from whence it has spread through the ports of northern Europe. As the fossil wood of the Isle of Sheppey is frequently bored by these worms, whose casts are preserved in the fossil state equally with the wood itself, it may fairly be questioned whether the above story can account for the existence of these pests. Be this as it may, it is not the less the case that the teredo bores into the heart of the wood, and destroys the strongest carpentry with frightful rapidity. Thus at Dunkirk wooden jetties are so speedily eaten away that they require renewal every twelve or fifteen years; at Havre a stockade was entirely destroyed in six months; at Lorient wood only lasts about three years in the sea-water; and at Aix the hull of a stranded vessel was found to have lost half its weight in

six months, from the ravages of these animals. On our own coasts the same destruction is caused by this apparently insignificant enemy; at Southampton, Ryde, Brighton, Dover, &c., the teredo has destroyed jetties with equal rapidity to that observed on the French coast, as above cited.

When the teredo enters a piece of wood it is so small as not to leave any perceptible trace of the passage by which it entered; subsequently it increases until the bore of the passage it occupies is equal in volume to the little finger. It only attacks the interior of the wood it enters, and oftentimes the latter will break off before any external indication is given of the presence of the worm. In piles, or other works in the sea, the zone most affected is that immediately below the main level of the sea; occasionally the teredos extend their ravages below the line of low water of the equinoctial tides, but they rarely mount higher than the line of high tide at neaps. It is believed that they cannot exist under mud so compact as to exclude air; and there are some local irregularities in their distribution hitherto unaccounted for; that is to say, they are often found in some parts of a roadstead or harbour, and not in others.

Engineers have endeavoured to prevent the ravages of these creatures upon jetties or fascine banks, by either covering them with nails or by sheeting them with copper, by coating them with verdigris or cement, or by impregnating the wood with some saline solution. Of these methods, that of covering the exposed surface of the wood with nails, about $\frac{1}{2}$ inch square at the head, appears to answer the best; but in spite of all the care and attention with which it may be performed, its successful results are always problematical. Mr. Hartley, of Liverpool, asserts that the green heart wood of Demerara is not subject to the attacks of the teredo, and the Sabicu wood, from the same colony, is said to possess the same property; but these are the 'only known exceptions to the rule. All other woods—oak, teak, fir, elm, alike—whether hard or soft, yield rapidly.

There are also other small worms, which do not attack the heart of the wood, like the teredo, until, at least, they have destroyed all the outer parts. Their ravages are, to a certain extent, combated by covering the outside of the wood by thin slabs of the same description, which are removed as soon as they are eaten, and replaced by others.

The details connected with the construction of lock-gates for harbours, and of the various sluices, do not differ in principle from those previously described in Part II., page 70, and subsequently, of this Treatise; nor do they involve other considerations connected with the pressure of the water than those contained in the sketch of the science of Hydrostatics as applied to this branch of special construction in Part III. The facilities to be provided for unloading, such as cranes, &c., will also be found by referring to the chapter on Docks, in Part II; the lighting of harbours is a detail connected with the subject of Lighthouses.

CHAPTER VII.

IMPROVEMENT OF RIVERS.

THE precise order traced in the synopsis, for the examination of the general principles of this branch of Civil Engineering, has been departed from a little, for the purpose of keeping the greatest number of phenomena connected with the tidal action before the reader at the same time. But it will be necessary to repeat occasionally some portions of the preceding chapter in order to explain fully the causes and effects of the modifications produced upon rivers by natural and artificial means, or to trace the laws which regulate their flow and influence the outline of their beds.

Rivers are, in fact, the channels by means of which the water originally evaporated from the sea, and falling upon the land, is returned to the parent source. In almost all cases it

is found that towards the interior of a country the ground rises into mountain ridges of variable elevations, and a geological investigation of the successive strata met with in the passage from the sea to the summit of these ridges, generally speaking, shows that the latter are composed of more ancient strata than those nearer the shore. The water falling upon the loftier hills either flows off rapidly, if the rocks be of an impermeable nature, or it is partially absorbed, to be again given out in accordance with the ordinary laws of hydrodynamics; or, becoming frozen at the highest points of the ranges, it gives forth, upon the limits of congelation, streams of considerable constancy of volume. In many mountainous districts lakes are frequently to be found which feed rivers, discharging, in this secondary manner, the waters conducted into the lake by the numerous smaller affluents. In some cases rivers rise in plains, and are fed simply by springs given forth by loftier ranges of permeable strata surrounding the plains. But the largest rivers, and those which are the most constant in their volume, are derived from the mountain ridges, situated above the line of constant ice, rising from wide tracts of table-land.

It may be stated generally, that the superficial configuration of the globe presents a series of such ridges and valleys, either of a simple or a complicated character; that is to say, any particular district consists either of only one system of hills, or of a principal and of several subsidiary chains, which again may either be parallel, perpendicular, or oblique to the principal ridge. The subsidiary chains are accompanied by subsidiary valleys, and the elevations of both decrease in proportion as they become more and more removed from the dominant ridge. It is to be observed, that the secondary valleys, especially when they are perpendicular to the direction of the main valleys, present much steeper profiles, both longitudinally and transversely, than these do; and the several valleys thus formed present at their lowest depressions a channel into which the waters draining from the surface of the

high lands, or those released by laying bare the edges of any water-bearing strata, pour from all sides; the volume of the stream thus collected depends upon the length of the valleys, the nature of the materials they intersect, and the more or less equal distribution of rain upon the upper lands. The existence of dense forests, or other circumstances able to retard the evaporation, have also great influence upon the constancy and volume of rivers.

Rivers present in the whole of their course, from the point where they rise to that in which they fall into the sea or some other river, the following circumstances:—their width increases as they advance, and their longitudinal section, excepting in some extraordinary cases, consists of concave curves, both at the bottom of the beds and at the surface line, although these curves are not necessarily concentric or parallel to one another. The courses of all rivers are so devious that it is an invariable rule that their length, measured upon their longitudinal profile, is greater than the rectilinear distance between their extremities. If the river fall into a sea, or another river, whose levels are exposed to variations, whether periodic or not, the transverse and longitudinal sections of the one thus falling in are exposed to variations beyond the influence of their own waters. Should the variations of the receiving channels be subject to tidal action, the subsidiary rivers will follow the usual laws; the neaps and the springs, the ebbs and the floods, will act upon them in an analogous manner, but in a different degree, to what they do on the sea.

In almost every instance the great mountain ridges are composed of the granitic or other primary rocks, rising through and upheaving the more recent sedimentary deposits. Owing to some law not hitherto explained, the principal axes of the ridges do not occur in the center of the continents or large islands, but they are always found to be nearer to one of the bounding shores than the one opposed. It follows that the general inclination of the land from the ridge towards the

sea differs on either side, and that in one case a long and
gradually inclined slope follows the mountainous region,
whilst in the other the slope is narrower and more rapid.
Illustrations of these laws may be found in all quarters of
the globe; it may suffice to cite at present the general
disposition of the European continent, which falls away
gradually towards the north from the great range formed
by the Balkan, Carpathian Alps, and Pyrenees, whose
main general direction runs from east to west; whilst
towards the south the rate of fall towards the Mediterranean
is considerably greater. But it is not to be supposed that,
although the main lines of elevation of a large geographical
district are marked by great regularity, the direction of the
flow of its rivers is equally constant. It often happens that
subsidiary mountain chains are thrown up in directions
parallel to those of the main ridge, and under those circum-
stances the rivers may be compelled to flow between them in
a direction transversal to the normal inclination of the
district. Thus, the Danube and the Mississippi both run in
directions parallel to the ridges, or back bones, as they are
rather appropriately called, of their continents; whilst the
greater number of the watercourses, and the general incli-
nation of the respective continents, follow directions precisely
opposed.

As the land falls away from the central ridges the rate of
inclination diminishes, and in following the downward course
of the large rivers the fact previously mentioned may be
observed, namely, that the more recent strata are gradually
found to occupy the surface, and, as a general rule, their
power of resistance to the transporting power of water
diminishes in the same order. The longitudinal profile
which naturally follows from this law assumes a concave
parabolic curve, whose apex is situated at the point of origin,
and the velocity of the flow of the river decreases in propor-
tion as it approaches the sea. In the more elevated districts
the transporting power of the water is therefore greater, but

as the rocks of which they are composed are of a much more resisting nature, the effect it is able to produce in degrading the surface is, comparatively speaking, less than in the flatter districts near the outfall. Upon the primary rocks, then, we find that rivers have a very imperceptible action upon the outline of their beds, and that the materials they carry down are but little comminuted. Yet in floods, the blocks and fragments detached from the escarpments around the water-courses are sometimes carried forward, and broken and rounded by attrition during their progress; the distance to which they are carried varying with their volume and specific gravity, as well as with the volume of the river. Following a main valley we thus find that at a short distance from its origin nothing but large angular blocks are to be met with; successively the blocks become smaller and more rounded; they then become merely pebbles or gravel, and at length nothing but sand or silt.

In the large plains of the more yielding strata, rivers work for themselves beds, whose dimensions are more in accordance with the tenacity of the soil and the volume of water they carry. If the soil be of a degree of resistance unable to support the action of the stream, the banks of the river will yield, and both the depth and the width will increase should those dimensions not be sufficient to ensure the discharge of the water. On the contrary, should they be already in excess, the width will be diminished by the deposition of the materials brought down by the floods. The geological, and, to a certain extent, also the mechanical, nature of the formations traversed affect the volume of the rivers flowing through them, by the greater or less facility with which they part with the rain-water falling upon them. Such rocks as the granites and compact limestones, especially the lias, allow it to escape almost as rapidly as it falls; the rivers passing over them must, therefore, be variable in volume, and if supplied by a large watershed, frequently of a torrential character. The denser clays, such as the Oxford or the London clays, part

with the water falling upon them rather more slowly than do the class of rocks last mentioned; but the oolites, and the loose open sands, absorb the rain as it falls, and yield it again to the watercourses with great regularity.

Dubuat ascertained by direct experiment the ratios of the volumes of different materials transported by running water with different rates of flow. Thus, he found that

					ft.	in.
Clay, fit for pottery, was removed by water having a velocity per second of					0	$3\frac{1}{6}$
Fine sand . ditto . . . ditto . . ditto .					0	$6\frac{1}{4}$
Gravel, about the size of peas . . ditto . . ditto .					0	$7\frac{1}{2}$
Ditto . ditto . beans . . ditto . . ditto .					1	$0\frac{3}{4}$
Shingle, about 1 inch diameter . . ditto . . ditto .					2	$1\frac{1}{2}$
Flints, about the size of a hen's egg . ditto . . ditto .					3	4
Broken stones . . . . . ditto . . ditto .					4	0
Soft rocks begin to yield with a velocity of . . . ditto .					4	4
Rocks, with distinct stratification . ditto . . ditto .					6	0
Hard compact rock . . . . ditto . . ditto .					10	0

Very moderate velocities, it thus appears, are sufficient to remove the materials usually found near the outfall of rivers and in large flat plains. The destructive action of the water is also increased by its chemical action in decomposing the materials exposed to it, by the beating of the waves, by the abrasion of floating ice, by the alternations of dryness and humidity, and, above all, by frost. Aquatic plants serve to defend the beds of rivers, provided the depth of water be not very great.

In all large valleys there may be observed traces of a previous geological action of rivers very different from that which they exercise at the present day, in degree at least. The soil, in such positions, consists of alternate layers of sand, clay, peat, and rounded pebbles, whose dimension diminishes as we proceed from the source, and which often are entirely wanting at the embouchure of the river. Through these layers, often of great thickness, the rivers run in channels of a dimension frequently much in excess of those

they would themselves be able to form. In the valleys of such rivers as the Rhine and the Seine, particularly, it appears that, at a period comparatively speaking recent, the surface of the country must have presented a series of lakes communicating with one another, like the vast chain in North America, and in these lakes the materials brought down by the floods must have accumulated. By some violent change these lakes appear to have been destroyed, perhaps by the gradual recession of their lower barrier, in a manner similar to that in which the barrier separating the Lakes Erie and Ontario is disappearing under the abrasion of the Falls of Niagara. But, however this may be, it is certain that the present volume of the European rivers is not sufficient to account for the immense deposits of diluvial matter through which they flow. And, in many cases, it is equally certain that the materials they now transport in the lower part of their course are derived from the previous accumulations of diluvium, rather than from the ridges from which they derive their supplies of water; and that these rivers now carry forward silt and mud much more frequently than they carry gravel of any considerable volume.

The manner in which rivers fill up, or raise, their beds, is a subject involved in some obscurity, or at least it depends upon causes which are often purely local. In many rivers the tendency of the water is rather to lower the bed, especially when it runs upon hard rocks, than to deposit the detritus brought down from the upper districts; and this tendency to deepen the beds is principally confined to the upper and more rapid portions of the course. The detritus in these portions is deposited in the various small branches, or bays, or, in fact, in any positions where a sudden change takes place in the rate of flow; and, when this law is skilfully applied by the engineer, it may be made to co-operate very efficaciously in the improvement of the course of the stream. But in the lower portions of the river, where the descending velocity of the water is destroyed by the meeting with the sea, the sand and mud are deposited gradually all over the

surface of the bed, giving rise to the deltas which are so characteristic of the mouths of rivers, particularly in tideless seas, such as the Mediterranean and the Gulf of Mexico.

According to the natural laws of gravity the velocity of the waters in a river would continually increase, agreeably to the rates of inclination of its bed, did not the friction upon the sides and the bed increase at the same time with the velocity, and in a much greater proportion. The friction also modifies the rate of flow of the several separate portions of the transverse section, causing it to be greater in proportion to the depth or volume over any particular part of the contour. There is, in almost all rivers, a zone where the depth is greater than in the other parts, and where, consequently, the velocity is greatest; this zone is called the "thalweg" by foreign engineers, and forms usually the navigable channel. Beyond it there are frequently other zones of still water, and in some cases these are characterised by currents flowing in an opposite direction to that of the main stream. In the thalweg itself, also, the velocity is not the same at the bottom that it is at the surface, where in rivers of ordinary depths it is at the maximum. It is usual to consider the mean velocity to be about four-fifths of that of the maximum.

The following table is extracted from the "Cours de Construction," by Sganzin; it shows the velocity of some of the most important rivers, principally in western Europe.

			ft.	in.
Mean velocity of the Seine, below Paris . . . per second			2	3
„ Thames at London, flood tide	„		3	0
Velocity of the Tiber at Rome, low water		„	3	4
„ Danube at Ebersdoff	„	„	3	6
„ Loire	„	„	4	4
„ Rhone at Arles	„	„	4	10½
„ „ Beaucaire	„	„	8	6
„ Durance below Sisteron	„	„	8	6
„ Maragnon, S. America	„	„	13	0
„ Rhine varies from 3 feet 2 inches to about		.	14	0
„ of a torrent produced by the melting of snow by the sudden action of a volcano		.	25	7

From the circumstances connected with the origin and subsequent flow of rivers, it follows that their volumes are exposed to considerable variations. Thus, the melting of a fall of snow, or a sudden storm, may cause the waters to rise in a very anomalous manner, producing in those parts of the course which are beyond the influence of tidal action serious modifications in the velocity and depth of the water, as well as in the cross section. It becomes important, therefore, before commencing any works for the improvement of a river, to ascertain the precise range of its variations of volume, and the numerous causes which may affect, not only the district drained by the principal stream, but also those of its affluents. Indeed, when rivers are of great length it frequently happens that the floods of the various subsidiary hydrographical basins occur at very distant epochs, and introduce numerous causes of irregularity in the flow. As, for instance, in the case of the Mississippi, the freshets from the upper valleys of the Mississippi and Missouri come down at different periods from those of the Ohio and Tennessee valleys, and, generally speaking, at a later period of the year. It is observed that the floods of the Ohio, under these circumstances, cause the waters of the Mississippi to be, as it were, penned back for a considerable distance; and equally the floods of the Mississippi occasionally pen back the waters of the Ohio for many leagues. The same remark will apply to most great rivers; but, in our own country the extent of the hydrographical basins is not sufficiently great to allow of much irregularity of this description; and we may consider with tolerable safety that our rivers, above the influence of the tides, are at the lowest in the months of June, July, August, and September, and that the floods occur in the months of December, January, February, and March.

Under ordinary circumstances we find that the banks of a river resist less than the bottom, and that the width proportionally is greater than the depth. The tendency of the constituent particles of the banks to fall down by the effect of

gravity adds to this excess of the one dimension over the other; and as the larger and more solid materials thus carried down from the sides remain at the bottom, they also serve to augment its stability by their greater resistance. In long level plains the velocity of the stream necessarily diminishes, and any accidental obstacle acquires increased power to deflect it from its natural course, which would be upon the line of greatest longitudinal fall. Should the bank be of a harder and more resisting nature on one side than the other, or should any natural or artificial projection exist, the stream will turn towards the other side; and its bed may thus become sinuous, and present such an increase of length as materially to retard the flow of its waters. In winter, it is also to be observed that, if the upper surface be frozen over, the whole of the abrasive action of the stream is exercised upon the bottom, which it will deepen so long as the water thus flows, as it were, in a pipe.

The researches of Guglielmini, Manfredi, Frisi, and Dubuat, may be consulted with signal advantage by engineers about to undertake works for the improvement of rivers; and of late years the notices of Messrs. Stevenson and Scott Russell, with the records of what has been executed in the United States and France, will be found to throw considerable light on the subject. It may be, however, sufficient at present to call attention particularly to the following laws deduced by D'Aubuisson, viz.—that the resistance of elbows or deviations is generally small; and that the current acting upon the concave bank destroys it the most rapidly, and gives rise to an increased depth in front of it, whilst the deposits and silting take place near the convex shore. It may also be observed that in mountainous countries rivers run close to, and are deeper near, the feet of the steepest hills, especially when these are exposed to the prevalent winds of the locality. And, lastly, it will be found, in rivers flowing over a sandy or gravelly bed, that there exist a series of zones in which the water retains a very slight velocity with considerable com-

parative depth; and that at other parts the bed rises in such a manner as to form bars, over which the water flows in a shallow rapid stream. These bars are generally situated near bends of the stream, and they serve to retain the waters flowing from the upper part of its course.

It follows from what has been said above, in this and the preceding chapter, that the works required for the improvement of the channel of a river may be directed either to regularize its flow in such a manner as to retain a sufficient depth of water for the purposes of navigation or of adaptation to manufacturing or irrigation uses; or simply to defend the surrounding country from the ravages of inundations, whether they be caused by floods from the upper districts or by the tides.

The first inquiries to be made in either case must be directed to ascertain all the variable conditions of the flow and volume of the river, the nature of its bed, and both its plan and section. As far as regards the adaptation of any stream to manufacturing and irrigation uses, the principal point to be decided will always be the height to which the water may be penned back, because evidently upon this, to a great extent, will depend the power it can produce and the surface it can irrigate. But with respect to its adaptation to the purposes of navigation, the questions of detail become more complicated. It frequently happens that the transports only require to be effected in one direction, and that they can only be effected under certain conditions of velocity and depth. The width to be given to the new navigable channel may also depend upon circumstances extrinsic from those of the river itself, so that a careful examination of the commercial relations of the district is as necessary as that of its physical nature.

When the upper part of any hydrographical basin is situated in a densely-wooded country, the stream is frequently capable of being rendered fit to transport floats or rafts, by giving it the breadth and depth required by means of a series

of artificial basins so disposed as to allow the water to escape at stated intervals, in flashes, upon the top of which the rafts are carried forward to the next basin. This system is only applicable to mountain streams with a small depth of water, and to such countries as produce much timber; it can, therefore, be seldom required in our own country, although in the colonies it might often be of great service. The most efficient mode of forming the sluices seems to be to construct retaining walls at an angle from the banks towards the center of the down stream, so as to reduce the open way in the axis of the river to that which is barely necessary to allow the rafts to pass. This open way should be continued for a short distance parallel, until arriving at the sluice, beyond which it widens out again. The width between $a\ b$ and $c\ d$ may vary from 24 to 13 feet as a mini-

mum; the length should be about $2\frac{1}{2}$ times the width. A sluice, working upon horizontal hinges at the bottom, and maintained in its position by a locking bar at the top, so that directly the bar is removed the sluice may fall, is used in some cases; whilst in others, the water is penned back by means of a series of movable blades resting against a set-off in the stone sill at the bottom, and a locking bar at the top, which is not withdrawn until all the blades are removed. With the latter arrangement the velocity of escape of the water is somewhat diminished, and the danger from the cataract thus produced, both to the raft and to the building of the dam, is diminished. The minimum clear depth of water over the sill, at the moment of flashing, should be about 1 foot 8 inches.
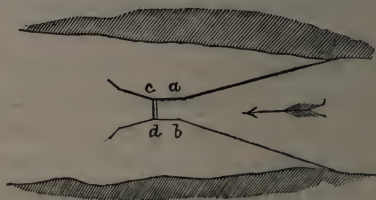
The best position for the opening of the sluice, so far as the conditions of the flow of water only are concerned, is in the centre of the stream; but if there be a towing path, it is

advisable to bring it as near to the latter as possible. It may also happen that in some positions it will be necessary to join a lock to the flashing sluice, in which case the best position for the lock is unquestionably in the still water on the opposite side to the sluice. The side walls of the lock chamber, and the floor of the tail bay, with its retaining walls, must be protected against the effects of the cataract from the sluice.

When it is possible to obtain, either artificially or naturally, a depth of about 3 feet, a river becomes navigable for barges. If the rate of fall in the longitudinal direction exceed from 7 to 8 in 10,000, the barges can only descend loaded. It is usual, however, to regard an inclination of 1 in 2000 as the maximum which admits of transport in the two directions of ascent and descent. The river Rhone has an inclination of from 7 to 8 in 10,000, as quoted above, and by the aid of a class of steamers constructed especially for that river, with some peculiar arrangements of their machinery, the ascending navigation is carried on with tolerable success. But on the river Lys, in Belgium, where the haulage is performed by horses, the rate of flow, produced by an inclination of 1 in 2000, might render the ascent difficult were it not retarded by the aquatic plants, which it is strictly forbidden to cut.

Barges naturally vary much in their dimensions, according to the nature of the river upon which they are employed. The extreme limits of variation appear to be, in length, from 50 to 230 feet; in width, from 6 feet 6 inches to 23 feet; and in draught of water, from 2 feet 6 inches to 6 feet 6 inches. Evidently, then, it is important to ascertain the dimensions of those frequenting the waters of the main stream, or of any of its affluents, before commencing any works for the improvement of either the former or the latter.

In many instances it will be found sufficient for all ordinary purposes of navigation to regularize the outline of the bank nearest to the thalweg, so as to secure a uniform depth of

water, and a freedom from abrupt changes of direction, in the part of the channel close to this bank. The towing-path would then, naturally, be formed on the same side; but it is perhaps as necessary to lay down as a general rule, that a towing-path ought to be formed upon the bank under the prevailing wind. The conditions really affecting the determination of its position are that the haulage take place in as direct a line as possible, and that there be very few impediments to the passage of the ropes. It may occasionally happen that a second towing-path is required, but, generally speaking, in these cases the width need not exceed one-half of that of the principal path. Both of them should be kept at such heights as to allow of their being above the water line, so long as the navigation can be safely carried on; directly, however, the waters of a river rise to such a height as to cause the river to flow with a dangerous velocity, it is advisable that they become submersed, in order effectually to prevent the bargemen from attempting to proceed.

The width of a towing-path is usually from 12 to 13 feet; mooring-posts are required on the opposite bank. In passing under bridges the towing-path should be carried under the land-arches, if possible, so as to obviate the necessity for detaching the tow-ropes. When it is not possible to carry the path in this position, it will be necessary to insert rings into the masonry of the bridge, or to place mooring-posts in the banks, or to adopt some other method of attaching the boats during the period that the tow-rope is being carried forward.

But, in the majority of instances, it is necessary to do far more than merely construct towing-paths. The depth of rivers in the summer months is usually insufficient to allow the continuance of navigation; in other seasons the velocity may be too great; sometimes the thalweg may shift from one side to the other, or the banks may be exposed to be frequently washed away. The first object to be obtained is, then, to maintain the river in its bed, and to create for it a

channel of such dimensions as to ensure, at the lowest waters, sufficient width and depth; and the second, to regulate its velocity so as to ensure favourable navigation in either direction. They may be obtained, either by forming a series of reaches of still water in the bed of the river itself, communicating with one another by locks; or by means of a lateral canal; or occasionally by constructing a secondary bank, submersible whenever the waters rise above certain definite levels.

If the river flow under such circumstances as to form a succession of islands dividing its waters into two or more branches, advantage may be taken of this circumstance to divert into the main or navigable channel the waters usually flowing in the subsidiary branches, by means of submersible dams or by movable barrages. It is also possible to convert the main channel into a canal, by forming a lock at the extremity of such a series of islands, and placing waste weirs upon the small communicating channels between them. Such a lock will also, of course, increase the depth of water reserved for navigation, and destroy any injurious velocity of the main stream; but even when it is found inexpedient to construct any works of this class, the fact of confining a stream within a regular channel, and thus concentrating its scouring action, will render great service by eventually lowering the bed of the river.

If the river suddenly diminish in depth on account of the widening of its bed, it may be improved by contracting the latter; the manner to be varied according to local circumstances. Thus, in the case of the Midouze, a river falling into the Adour, in the south of France, the widening out of the channel in several of its bends was corrected very successfully by planting aquatic trees, such as willows, osiers, &c., upon the banks, so as to leave a clear, regularly outlined, water-way, at the same time that all reefs or other projections in the channel were removed. When the velocity of the stream is small, this system appears to answer very well;

because the artificial banks thus formed soon become raised by the deposition of any mud or sand in suspension in the waters of floods, which is facilitated by the retardation of their flow in consequence of the obstacles formed by the trees, and as the roots of the willow tribe strike quickly they soon solidify the deposits. As the water-way becomes also thus contracted, there is at the same time created a tendency to lower the bed of the river and to cause the water to flow permanently in the open channel thus left. There is a great simplicity in the means adopted in this case; the materials employed are inexpensive and easily procured, and they possess this advantage, that they do not in any way interfere with the normal régime (or conditions of flow as to volume and velocity), in the open channel, at least.

In rivers exposed to sudden and violent floods, however, the trees, and the deposit around them, would be inevitably carried away; and it becomes necessary to construct the longitudinal banks required to concentrate the summer or low waters in a more substantial manner. But, in such cases, it is equally necessary to defend the usual or natural bank of the river by some system which shall enable it to resist the abrading action of the current. On many rivers, instead of constructing longitudinal banks, a series of transverse spurs are carried out into the stream, for the purpose of giving rise to corresponding pools of still water in which the silt or gravel carried down may be deposited. These spurs, in fact, are intended to exercise the same influence upon the stream of rivers that groins do upon the currents of the sea-shore. In both cases, however, their useful effect is very questionable; that is to say, when compared with their cost. Unless they are in close proximity to one another, the counter-current produced by these spurs is found to corrode the banks in a serious manner on the down side of the projection. If they are very close together, their developed length will be found to be nearly equal to that of the more logical system of longitudinal banks; and in the latter case, moreover, there

is less danger to be apprehended from the changes of direction produced by the irregular interferences with the line of the current. Experience appears to warrant the assertion of the general rule, that the most effectual method of deepening the bed of a river, and of regulating its flow, is to confine it between longitudinal banks, which may occasionally require lateral openings or waste weirs, so as to allow any sudden freshets to escape directly they attain a dangerous height.

The submersible banks, or dykes, as they are sometimes called (and the name will be retained for the purpose of designating more clearly the difference between the dykes and the banks), may be executed either in rough blocks of stone, or concrete, of masonry, of woodwork, of fascines, or of panniers filled with gravel or with rubble-stone. The feet of the banks may also be protected in the same manner; and if any portion extend much below the permanent water-line, a combination of several of the above systems may be employed, as in the case of the banks of the Rhine. In almost every case, however, the determining motive in the choice of materials is to be found in their relative cost. As the two classes of works, viz., those for the defence of the banks and the construction of the dykes, are so nearly identical, the description of the former, by far the most important, will be given in the greatest detail.

The rubble facing of river banks may be resorted to when stone is plentiful and at a very low cost, for it is to be observed that the quantities required are very considerable. One peculiar advantage of this system is that the rubble easily slides down into any place where the water has attacked and undermined the banks; and it may be executed under almost every condition of the level of the water in the river. The largest stones which it is possible to obtain ought to be employed, because they are displaced with the greatest difficulty. The slopes, when finished, should be dressed tolerably smoothly to a minimum inclination of $1\frac{1}{2}$ to 1; the

thickness must depend upon the nature of the bank to be supported, and the degree of erosion it is required to compensate.

When stone is dear, the slopes may be pitched in the portion above the usual summer level; this pitching, however, does not support the banks, but only serves to defend them against any erosive action of the currents or descending ice. In the execution of this pitching the most important part is to be found in the foundations, which must be able to resist the undermining effects of the current. If the bed and sides of the river be of a solid nature, loose rubble may be employed; but if they be of a nature to yield easily, it may be necessary to defend the feet by a single, or even by a double, row of piles; the woodwork being kept as low as possible in all cases. The inclination may vary from 1 to 1, to 2 to 1; the longer slopes requiring a less thickness of pitching, and resisting the action of the currents more effectually; at the same time they will be found to carry waves to a higher point, if the river be sufficiently wide to allow of their formation. The thickness will be regulated by the rate of inclination and the force of the currents; but it is usually from 9 to 14 inches at the summit, and increases at about the rate of 1 inch to
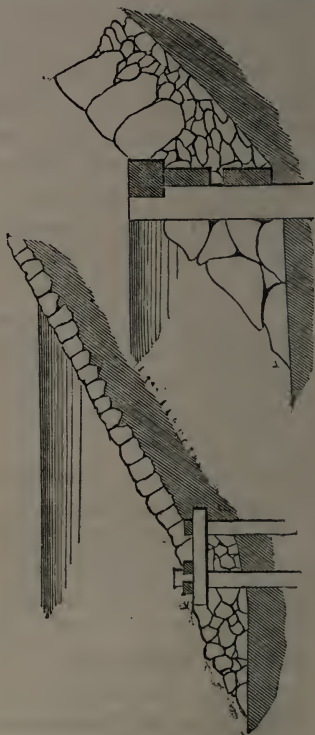
every foot of additional depth. In order to resist the action of the currents at the water lines, the courses should be inclined, or, at any rate, they should not preserve their horizontality for any great distance.

Slopes may be protected from the effects of a sudden flood, when rapidity of execution is desired, by means of a timber facing. Guide piles are driven, either vertically or in an inclined position; they are connected at the top by whales, and on the inside they are lined by planks laid horizontally, and backed by earth. This method of defending banks of rivers is very costly, and can only be employed definitively in positions where timber is plentiful, land valuable, and the length to be protected not very considerable. It has been adopted on the banks of the Sceldt, and in some of the Atlantic cities of the United States. On the banks of the upper Po, in the Piedmontese
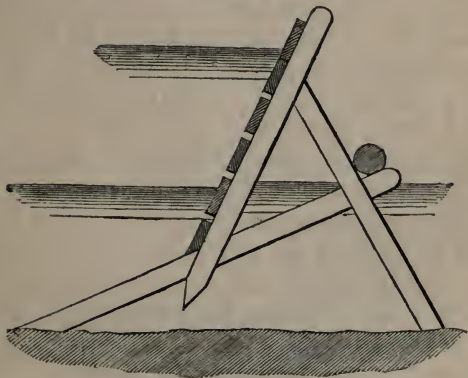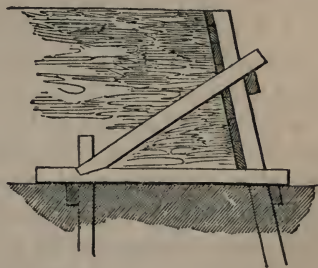
dominions, a very economical system of temporary wooden

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defences was introduced by an Italian engineer, of the name of Magistrini, which has answered very well in every instance where it has been employed, for the purpose of turning aside any current acting upon projecting spurs or abrupt elbows on the river banks.

The Piedmontese engineers have also endeavoured to introduce a system of defence walls consisting of triangular prisms of concrete, dressed eventually to a slope of 45° with the horizontal line. In other cases, as upon the banks of the Medway, river walls have been executed by forming a general bed of concrete, which is further protected by rubble-stone pavement, tied down by a series of stakes driven into the bank itself.

Fascines are formed by tying together a great number of small twigs of brushwood, laid longitudinally, by other twigs placed at intervals varying with the diameter. The wood ought to be from five to six years' growth, the small and large ends being respectively kept in the same direction, and at least two-thirds of the total quantity used in a fascine should pass from one end to the other, nor should any twig exceed 4 inches in diameter. Small fascines are from 5 feet to 6 feet 6 inches long, and about from 1 foot 6 inches to 3 feet 6 inches in girth at the large end. In Flanders and Holland the length is usually made from 8 to 13 feet, and the girth in the center from 1 foot 4 inches to 1 foot 8 inches; and upon the Upper Rhine the length is made from 13 to 16 feet, with a girth of from 3 feet 6 inches to 5 feet 6 inches at the larger end, and from 1 foot 8 inches to 1 foot 10 inches at the smaller. Sometimes the fascines are tied together at the ends, so that the small extremity of one may join the large extremity of the other, and the name of "sausage," or "gabion," is given to the assemblage. Military engineers make their gabions about 20 feet long, and 3 feet in girth on the mean, with bands at distances of from 1 foot to 1 foot 6 inches; in Holland the gabions are made from 24 to 27 feet long, from 1 foot

4 inches to 1 foot 8 inches in girth, and with bands at every 6 inches apart; and upon the Upper Rhine the gabions are made from 2 feet 6 inches to 3 feet 4 inches in girth.

In Flanders and Holland, when a bank is to be protected by fascines, if the corrosion take place above the ordinary water line, and the natural slope of the ground below be such as to support the weight of the bank, the fascines are laid in horizontal courses, with the small end towards the land and the butt end to the water. The ends of every succeeding layer are set back from the line of the layer below it, so as to form a regular batter, and the whole body is tied together by means of stakes 4 feet long driven through each fascine as it is placed. The heads of these stakes project from 6 to 8 inches, and they are tied together by hoops passing alternately in and outside of the heads. Gravel, clay, sand, or shingle, are then firmly rammed upon the fascines, so that their surface becomes perfectly level before proceeding to place another layer. The batter of a slope thus built up in fascines may vary from $\frac{1}{3}$ and $\frac{1}{2}$ to 1 base to 1 in height.

When the bank is corroded below the ordinary water line, the course usually adopted is, to form a species of raft of gabions strongly tied together and fixed into the banks by stakes, with their ends projecting into the stream. Other gabions are placed upon these in a direction parallel to the bank; and fascines alternately crossing one another in the body of the raft, but presenting always at the river end their smallest extremity, are laid upon this description of grating. The several layers of fascines are joined together by stakes, round which bands are placed as before, and the whole structure is sunk by being loaded with gravel or stones, forming, in fact, a species of elastic matlass adapting itself to the form of the river-bed. The force and velocity of the current modify to a certain extent the resistance of the gabions; and it is for this reason that in the districts of the Upper Rhine the dimensions given to the gabions are greater than those adopted where the river runs more sluggishly.

Upon the banks of the Rhine panniers filled with gravel are occasionally employed. They are formed of osiers or willow-twigs woven together in the form of baskets, about 6 feet 6 inches long by 3 feet 4 inches high and 2 feet wide, when rectangular; the length is made about 7 feet when the panniers are triangular, the sides measuring 4 feet 4 inches; when they are circular, the length is made 10 feet, and the girth about 7 feet. These panniers are thrown down, sometimes at random; at others they are sunk over the positions they are intended definitively to occupy, and fastened by means of stakes. In several instances, large hollows in the banks of rivers in these districts are filled in with panniers of the above description, and the upper surface is further protected by means of a pitched stone slope laid in the usual manner.

The use of fascines can, however, only be recommended in countries where more durable materials are extremely expensive, or where great rapidity of execution is required. They are exposed to very rapid decay, and to the attacks of numerous animals. In England, they are hardly ever employed by other than the Royal Engineers; and it is in Holland only that they are habitually employed in the formation of longitudinal submersible dykes for the regulation of the channels of rivers. Whatever description of material be adopted, the most important point to be observed is, that the work for the defence of a bank should be executed with the greatest rapidity, and before the corrosions can attain any dangerous extent, which might allow the formation of any secondary branches, or any permanent alteration in the régime of the river.

In all works intended to improve the navigability of a river, extreme care is required in attempting to alter its natural conditions, whether of width or of depth, because the results of any interference with them are always very uncertain. It is preferable at all times to maintain the river within the limits nature appears to have traced for it under its normal flow, rather than to endeavour to introduce great modifications, even though they may appear highly desirable.

Thus, in several instances, when it has been attempted to shorten the course of rivers by diverting them into new and straighter beds, the water has eventually formed for itself a course of precisely the same character as the original one. This is particularly true with rivers that run upon a sandy bed, when they follow a sinuous line, and it is attempted to shorten the distance between any of the principal beds; for the slightest inequality in the resistance of either the bed or of the banks will give rise to currents such as are able to overthrow the new works. It may be laid down as a law, that the straightening of the bed of a river is only to be effected to a limited extent, one which will depend upon the nature of the materials over which it flows, and the volume of water it carries.

It may be possible to improve the navigability of a river either by dredging, or by the closing up of the secondary branches, without resorting to the construction of submersible dykes; and at almost all times those operations are productive of advantage, if executed with proper precautions. Thus, dredging may be resorted to, for the removal of any shoals in that portion of the course of a river where the navigation is designed to take place. But in some cases, as, for instance, when the water is kept back in a series of pools by means of such shoals, their removal may be attended by the lowering of the water line in all the upper parts of the river. The nature and mode of formation of such shoals must therefore be carefully ascertained before an attempt is made to remove them.

In closing the small branches which run between the subsidiary islands so frequently to be met with in rivers, the course usually adopted is, to carry out the dam from either side towards the center. In proportion as the dam advances the waterway becomes contracted, and naturally the velocity is increased to such an extent as to render the closing of the central portion a very difficult operation, because the bed is deepened, and the materials thrown in are often carried away

immediately. Sometimes the aperture is closed by driving piles in front of it, between which hurdles are placed so as to diminish the current; sometimes sheet piling is driven; and occasionally old boats or pontoons laden with earth or stones are sunk. Under all circumstances, it is necessary that the materials required to carry the dam up to its full height should be prepared beforehand, so that no opening should be left through which the water should flow. Loose rubble-stone dams are used in some places, and they become eventually watertight by the deposition of the mud and silt brought down by floods. Fascines are used in other cases, either by being thrown down at random, or by being sunk in large rafts in the manner adopted in Holland and Flanders.

The best position of the dam closing such small branches is a subject of some obscurity. When it is placed at a considerable distance below the point of bifurcation, the water becomes stagnant before arriving at the dam and deposits the silt required to render it watertight. When it is placed close to the point of bifurcation, the currents and floating ice are likely to damage its construction; and moreover the length in such positions is considerably increased. The only general rule appears to be, that the dam should be placed sufficiently near, but below the extremity of the island, to allow the alluvial deposit to reach it easily.

A very important observation is to be made with respect to the diversion of the waters of secondary branches into the main stream; namely, that the depth of the latter will be but slightly increased if the river flow freely, because the volume of water discharged increases more rapidly than the height. Observations upon the meeting of rivers pointed attention originally to this law, and theoretical reasoning confirms it. Some interesting facts connected with this subject will be cited hereafter; but it may be now observed that the effect of any dam or dyke which offers an obstacle to a current is to produce a contraction of the waterway, causing the plane of the water to rise on the up side and to lower on the

down side. The inclination of the surface in the portion so contracted is naturally increased, and it is possible that it may be so to such an extent as to interfere seriously with the navigation. If the bed of the river itself be of a light and easily-moved nature, it is equally possible that the increased velocity of the current may deepen it; but, under ordinary circumstances, the materials thus removed are only displaced, for they are deposited in the lower part of the course, where the river in fact begins again to widen out to its natural dimensions. The practical rules usually admitted by engineers in works connected with the narrowing of rivers for the purpose of increasing the depth may be briefly stated to be as follows:—

1. The longitudinal dykes should never be carried to a height above the mean level of the water in the river; the usual height above low summer water level is 2 feet; during floods, they should be entirely under water. 2. The velocities of the different channels vary in the inverse ratio of the cube roots of their widths. 3. The cubes of the heights are in the inverse ratio of the widths of the beds. 4. As much as possible it is advisable to preserve the natural waterway, and to make the capacity of the narrowed pass equal to that of the ancient bed in such portions as are free from irregularities. If it be necessary to displace the river, it should be directed, in preference, to the bank or portion of the channel most likely to yield to the scouring action of the waters.

The attention of engineers was called to the peculiar phenomena connected with the junction of rivers by a very remarkable letter or report by Gennété, an Italian engineer, addressed to M. de Raet, burgomaster of the city of Leyden, about the year 1755. In this letter he showed that a large watercourse could receive all the water brought into it by an affluent of considerable volume, without any sensible augmentation of the height of the water line, or without any increase in the width of the bed. The reason he assigned for this was, that at the same time that the volume was increased the

velocity was augmented in such a proportion as to compensate for the effects it would be natural to expect under the above circumstances. At the same time he showed that the formation of new channels would not lower the water line in any main stream, but only retard its velocity. He cited in confirmation of his views the facts that the Danube, after receiving the Inn, neither increased in width nor in depth; nor did the Rhine occupy a larger bed in passing through Cologne, after receiving the Moselle, than it did in the upper part of its course. On the other hand, he observed that the Rhine, near its embouchure, divides into the several branches of the Waal, the Yessel, and the Rhine proper, without any sensible depression of the water line either in the parent stream or in the branches. It may be interesting to observe here, that it has been observed also in America, that the width of the Mississippi after the junction with the Ohio is even less than that of the former river above the point of junction.

Mr. Cressy, in his examination before the Metropolitan Sanitary Commission, gave a condensed summary of Gennété's experiments, and a series of translations from the tracts of the early Italian hydrographical engineers, collected and published in Florence in the year 1667. Notwithstanding the progress of science of late years, it does not appear that anything has been discovered to invalidate the truth of the general proposition thus enounced, that rivers do not necessarily increase in width or depth in consequence of receiving affluents, and the main principles sought to be established by Gennété, viz., that it would be useless to endeavour to lower the waters of rivers in deltas by making fresh channels, are still generally admitted. For more copious information on this subject, the reader is referred to the Italian collection, or to Mr. Cressy's evidence, before alluded to.

The interference with the regular discharge of the main stream by an accidental increase of volume in the affluent, which has already been noticed in the case of the Mississippi and the Ohio, has also been observed in Switzerland. It

frequently happens that the Arve, when swollen by freshets, drives back the waters of the Rhine as far as the Lake of Geneva; and Mrs. Somerville mentions that on one occasion the direction of the flow of the Rhine was actually reversed. At the junction of such rivers it is found, as might naturally be expected, that a long strip or tongue of alluvial land is formed by the deposition of the matters in suspension in the waters, especially of those in suspension in the filaments which directly impinge upon one another. The direction of this tongue of land is in the line of the resultant of the two streams, and consequently is longer and forms a more open angle with the respective axes in proportion to the velocity of their flow. It almost always happens that the alluvial plains thus formed are of singular fertility, and when the rivers flowing on either side are navigable, the position of the extremity is of incalculable commercial value. This was felt to be the case with the tongue of land between the Ohio and the Mississippi, and an attempt was made to erect upon it the city of Cairo. Unfortunately the nature of the floods of these two mighty rivers was not examined with sufficient care, and the embankments were not, originally at least, constructed of such heights or strength as to keep out the floods, so that the proposed situation of the city was often under water. It may also admit of question whether the construction of banks able to contain the waters of the floods would not eventually cause the extremity of the tongue of land to advance, so as in fact to leave a city thus built at a gradually-increasing distance from the point of junction. The financial results of this injudiciously-managed scheme were such as might have been expected, and may be in the memory of many.

The waters of two confluent streams, as was before observed, do not mingle for a distance depending upon their respective velocities, and to a certain extent upon their chemical composition. The elements which characterise them respectively may often be traced to a great distance; thus, in

the case of the Seine above Paris, the waters upon the right bank are charged with the calcareous salts brought down from the upper valley of the principal river, whilst those upon the left bank are charged with the magnesian salts and the earthy matters brought down from the valley of the Marne. This fact is, perhaps, more distinctly marked upon the shores of the great lakes and of the ocean; for the muddy waters of the Rhine may be distinguished from the deep-blue waters of the Lake of Geneva, and the stream of the Amazon may be traced in the Atlantic, at distances, in both cases, far removed from the points of their embouchures.

A cursory examination of a map will show that the law which appears to regulate the formation of the deltas or alluvial deposits at the mouth of all great rivers is, that these divide into a series of subsidiary branches before falling into the sea, and that they almost always project beyond the line of the sea-shore, forming, as it were, projecting promontories of a rounded outline connected with the original line of coast: the Volga, Danube, Rhine, Rhone, Po, Nile, and the Mississippi, Ganges, Irrawaddy, &c., may be mentioned as illustrations. The lands around these deltas are flat and marshy, and consist of sand and mud; the channels winding through them are shallow, and exposed to change in their direction and volume without any apparent cause. The rate of deposition depends upon circumstances equally beyond ordinary calculation, and varies in every particular river.

The formation of these deltas arises from the deposition of the matters brought down from the upper portions of the river courses, caused by the difference in the specific gravities of the fresh and salt waters, and the annihilation of the onward movement of the former by the tides or the littoral currents of the latter. The tendency to the deposition of alluvions is also increased by the diminished inclination and velocity of the rivers near their mouths, and in some cases this diminution is sufficient to cause the rivers to overflow the lands above the delta itself, so as to render it difficult to

ascertain its precise limits. The formation of the subsidiary
branches noticed in the deltas is to be attributed to the reflux
of the waters in the main channel, and they are the most
numerous in the deltas which advance with the greatest
rapidity and occupy the greatest areas. But if the littoral
current run with great velocity and transport any alluvions, it
will give rise to bars at the mouth of the branches; if it be
free from alluvions, it will disperse the materials it may
detach from the extremities of the deposit, or, deflecting the
line of outflow of the river, it will give rise to a delta
following the direction of the resultant of the two forces.
Occasionally also the tidal waves will give rise to a bar across
the mouths of the branches at the points where they begin to
neutralize the outward flow of the soft water.

The majority of the English rivers fall into the sea at the
bottom of large open bays, and in those cases the deposition
of the fresh and salt water alluvions takes place in the form
of banks or shoals in those portions of the bay where the
respective currents of the sea and of the river meet. These
shoals vary constantly in their outline and position in such
rivers as the Thames and the Severn, and in the Seine,
Loire, and Garonne in France; and form very serious impedi-
ments to the navigation. In many other cases, as in the
rivers upon the Suffolk and Norfolk coast, and upon the
southern shores of England, the deposits take place across
the mouths of the rivers, according to the law noticed in the
last paragraph. But it is to be observed that, although these
bars diminish the depth of water immediately over them, the
river above may often retain a very considerable depth;
indeed the effect of the bar is often precisely analogous to
that of a dam. Thus, the Rhone has rarely a depth of more
than 6 feet 6 inches in the passes of its delta, whilst at Arles
the depth is not less than 43 feet. At the mouth of the Po
di Volano the pass has only a depth of 2 feet 6 inches, whilst
about seven miles further up the depth is not less than 10 feet;

and the same fact has been observed at the mouths of the Nile and of the Mississippi, but to a far greater extent.

At the junction of streams in the interior, the same phenomena may be observed to take place as those which have been already noticed as occurring on the sea-shore, although of course upon a very diminutive scale. Should one of the confluents bring down much alluvial matter, and flow with considerable velocity into a stream of a different character, the deposit may take place either in the fan-like shape of a delta or as a bar; and in the former case it is possible that the stream may divide into a number of branches, whilst in the latter the relative depths of water over the bar and above it may present all the essential conditions of those connected with rivers discharging into the sea. But the absence of the tidal action gievs a greater fixedness and simplicity of character to the manner in which these deposits are effected, and consequently allow of their being treated with greater comparative facility, whenever it is desired to improve the navigation of a river previously obstructed by them. But it must always be borne in mind, whether it be a question of combating the natural operations of the laws affecting the flow of large or of small streams, whether strictly inland or in estuaries, that unless some other natural law of the same class be made to counteract the particular one producing the state it is desired to remedy, all engineering contrivances or mechanical operations will either be vain, or at most produce but a temporary effect. Nature must, in fact, be made to correct itself.

If, therefore, it be desired to obviate the inconvenience arising from the deposition of the alluvial matter across the embouchure of an affluent into a greater stream, and this deposition be found to be caused by the annihilation of the velocity of the affluent, in consequence of the greater velocity of the main stream, the only effectual mode of proceeding would be, to increase the velocity of the affluent by diminish-

ing its bed ; or perhaps, if it follow a devious course, by increasing the fall by means of a new and shorter channel. It would also, in some cases, be possible to effect the desired object by forming an artificial embouchure at some other point on the river, where the régime of the main stream might be very different.   But whatever precise details be adopted, they must resolve themselves finally into the means of securing an equality of velocity in the confluent rivers, and so directing the respective axes of their flow as to prevent the stream of the one from setting across the line of the other.

Should the deposit assume the form of an ordinary delta, and give rise to a subdivision of either or both the rivers into a series of small branches, the best course to adopt is, to form new beds for the waters brought down, of such sectional area and inclination as to ensure the meeting of the respective streams under those conditions which would allow the alluvial matters to deposit themselves upon lines of direction corresponding with the resultant of the two new channels. As the tongue of land thus formed would continue to advance, it would be necessary to provide for the inevitable changes it would superinduce upon the point of junction.

On the sea-coast, if it be desired to lower the water line in the branches of a delta, Gennété's experiments, and all subsequent experience, show that the most efficient method of proceeding is, to increase the velocity of flow by causing a greater volume of water to pass through a given channel in the same period of time, rather than by increasing the surface of the waterway.   This is especially the case when the bottom of the river is composed of a material capable of being easily removed, because the bed itself will be lowered in consequence of the increased transporting power of the water.   Evidently then, in such positions, the width of the subsidiary channels is the only element which is susceptible of modification by artificial means, at least economically, and it should in all cases be reduced as much as possible.   All the small branches which can conveniently be suppressed should be closed, so as

to concentrate all the action of the water upon the channels it is proposed to retain for the purposes of navigation. These remarks are principally made with reference to tideless seas; the difference in the system to be adopted where the range of the tides is considerable is substantially unimportant, and will be mentioned hereafter.

In the case of a bar formed across the mouth of a river on the sea-shore, human means are almost powerless if the littoral current bringing the alluvions be strong, and not susceptible of being diverted. To a certain extent it is possible to augment the depth of water above the bar by concentrating the outflow of the river, and guiding it by means of parallel banks in such a manner as to direct the scouring action of the land water so that it should remove the alluvions either into the deep sea or again into the littoral current which should carry them further on. But the success of such measures will only be temporary, and the history of the ports of Rye, Dunkirk, Aigues-Morte, and others, show that it is hopeless to endeavour to struggle against the ceaseless unwearying operations of nature. New channels may be carried out through a bar, and for a time kept clear by the scour of the upland waters and by dredging; but sooner or later the angle between the original outline of the bar and the projection of the new channel becomes filled in, and if the littoral current should not then be able to sweep off the alluvions carried to the front of the pass, the bar will begin to reform. The pass or channel must then be carried further out to sea, or kept open artificially at a constant and excessive cost. It is possible to direct the tidal action in some positions, so as to produce considerable modifications in the ordinary laws affecting bars, in the following manner—which is applicable to either of the cases connected with the entrances to rivers hitherto considered.

In the lower zones of rivers exposed to tidal action, the depth of the navigable channel may be increased by causing a larger volume of water to enter with the flood, and confining

its outflow during the ebb within the limits of the channel. If then a river divide into several branches, the subsidiary ones may be closed by means of dams, with sluices opening only with the flood, and so arranged that the water thus introduced into the secondary channels shall be forced to escape by the one it is proposed to deepen. This object may also occasionally be effected by causing the secondary channels to derive their supplies from the principal one at some point on the up stream; but it will generally be found that in such cases the velocity of the ebb tide will be inconveniently great for the ordinary purposes of navigation. In fact the secondary channels would become sluices, whose waters would act to scour the pass. The advantage proposed to be gained in these instances is to be found in the fact that a large quantity of water is forced to flow through a narrow channel, and the velocity is consequently increased, thereby enabling the river to remove the lighter materials of which its bed is composed. But the whole success of works intended to produce these results must depend upon the relative proportion of tidal water which can be made to enter, or upon the increase of velocity in the outflowing stream. It follows, therefore, that any diminution of the water surface at high tide is likely to affect seriously the power of a river to maintain a clear navigable channel, unless the latter be contracted at the same time in a corresponding degree.

The results obtained at Nieuwe Diep, upon the Clyde, the Dee, the Thames, and the Seine, confirm what has been above stated; and, moreover, the practical deductions to be made from them appear also to warrant the assertion that it is preferable to obtain the increased scouring action of the tide by forcing the water to flow to a higher point in the river, rather than to allow it to spread near the embouchure. The works of Nieuwe · Diep have already been described; those upon the Clyde and the Dee and the Ribble have consisted in the erection of longitudinal dykes parallel to the axis of the river, retaining the stream within a narrow channel during

the latter portion of the ebb, and in the removal of obstructions to the propagation of the tide wave to a greater distance from the embouchure than it had previously attained. In the Thames, the removal of the Old London Bridge, which acted as a dam to the tide, has been attended by an increase in the duration of the flood, and an increase of depth at high water varying from 1 foot 8 inches at Teddington to nearly 7 feet at Blackfriars Bridge. In the Seine, the concentration of the tidal action, by means of the lateral banks lately formed between Caudebec, Villequier, and Quillebœuf, has deepened the river a little more than 9 feet, partially destroyed the bore, and increased the duration of the flood tide one hour. Nor does there appear to be any reason why these results, so advantageous to the interests of commerce, should not be further developed, if the existing obstacles to the propagation of the tide wave into the interior were removed upon the two last-named rivers.

Precisely opposite results have attended the diminution of the scouring reservoirs naturally existing beyond the channel of the port of Ostend. The marshes or low lands, there flooded at every high tide, have been gradually reclaimed, and as the channel was not carried further up into the country, so as to create an artificial backwater whose conditions of discharge should replace those under which the waters over the low lands escaped, the silt brought into the mouth of the harbour by the littoral current has considerably diminished the depth in the entrance. Dredging and sluicing have been resorted to in vain, although conducted with all the practical skill and persevering energy of the Dutch and Belgian engineers. For, however powerful the effects of sluices may be, they are far inferior to those of the alternate currents of the flood and ebb tides spreading over large spaces. Great circumspection must therefore be exercised, and long, elaborate, and skilful investigation made, before any port or river is deprived of the scouring action of the tides. The alluvial deposits may perhaps tend naturally to diminish or to destroy

this action; but it must be retained as long as possible, and our efforts directed at all times rather to increase than to diminish its power.

Finally, it cannot be too often repeated that, before undertaking any works which may interfere with natural causes so complicated and so numerous as those which affect all river or sea engineering, the most cautious, patient, and at the same time comprehensive view of the whole subject must be taken. In the whole range of professional practice the questions connected with hydraulic engineering are the most abstruse, and require the assistance of all the collateral sciences, and the profoundest acquaintance with the great laws of nature affecting the configuration of the globe. Empirical knowledge is but of little service, and the local engineer, if devoid entirely of theory, is as likely to fall into serious error as to hit upon the truth, by trusting alone to his limited experience. And it is upon this score that we may account for the fearful waste of money, and the ruin of many ports, which have been entrusted to the care of those whom it is too much the fashion to admire in our own country under the specious title of "practical men." Extremes are dangerous in all things; and it must be understood that, whilst thus advocating the necessity for wider and more theoretically-scientific examination of the circumstances affecting the sites of any proposed hydraulic works, due appreciation is accorded to the value of local experience. Theory, practice, and science must mutually be brought to bear in all such cases, and the more of all of them the better. No one alone will suffice.

The only axioms which can be safely laid down are:—

1. That no change should be introduced in the natural régime of either rivers or the sea, unless absolutely necessary.

2. That all our efforts should be directed to bending the powers of nature so as to ensure their co-operation in bringing about the state of things we desire to secure. The motto of the hydraulic engineer should be that placed by Leupold at the head of his " Theatrum Machinarum Hydraulicum:"

<p style="text-align:center">" Artis est naturam imitare."</p>

APPENDIX.

TABLE I.—Coefficient of Discharge through Rectangular Orifices given by Poncelet and Lesbros. See Part III., page 52.

Head over Center.	Height of Orifice.					
	8 in.	4 in.	2 in.	$1\frac{5}{48}$ in.	$\frac{19}{24}$ in.	$\frac{19}{48}$ in.
$\frac{19}{48}$ in.	...	...	...	...	...	0·712
$\frac{19}{24}$ in.	...	...	...	0·644	0·667	0·700
$1\frac{5}{48}$ in.	...	...	...	0·644	0·663	0·693
$1\frac{7}{12}$ in.	...	...	0·624	0·643	0·661	...
2 in.	...	...	0·625	0·643	0·660	...
$2\frac{9}{24}$ in.	...	0·611	0·627	0·642	...	...
$3\frac{1}{6}$ in.	...	0·612	0·628	0·640	...	...
4 in.	...	0·613	0·630	0·638	...	...
$4\frac{3}{4}$ in.	0·592	0·614	0·631	...	...	...
6 in.	0·597	0·615	0·631	...	...	...
8 in.	0·599	0·616	0·631	...	...	...
1 ft.	0·601	0·616	...	...	...	...
1 ft. 8 in.	0·603	0·617	...	...	...	...
3 ft. 3½ in.	0·605	...	...	...	...	...

TABLE II.—Coefficient of Discharge over Weirs, given by Poncelet and Lesbros. See Part III., page 53.

Height over weir......	$\frac{19}{48}$ in.	$\frac{19}{24}$ in.	$1\frac{5}{48}$in.	$1\frac{7}{12}$in.	$2\frac{9}{24}$in.	$3\frac{1}{6}$ in.
Value of coefficient...	0·424	0·417	0·412	0·407	0·401	0·397

Height over orifice ...	4 in.	6 in.	8 in.	$8\frac{2}{3}$ in.
Value of coefficient...	0·395	0·393	0·390	0·385

TABLE III.—Loss of Head by Flow through Pipes, or Inclination necessary to maintain the Velocity and Discharge given in Table; the Quantity being expressed in Cubic Feet, and the Loss of Head in Feet Lineal.

Diameter, 0·5 in. Area, 0·1963 in.			Diameter, 0·625 in. Area, 0·3068 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·001363	0 012230	1·000	0·002131	0·009784
1·083	0·001476	0·014037	1·083	0·002308	0·011230
1·166	0·001589	0·015952	1·166	0·002484	0·012762
1·250	0·001704	0·018005	1·250	0·002663	0·014404
1·333	0·001817	0·020136	1·333	0·002840	0·016109
1·416	0·001930	0·022376	1·416	0 003017	0·017901
1·500	0·002044	0·024750	1·500	0·003196	0·019800
1·583	0·002158	0·027202	1·583	0 003372	0·021761
1·666	0·002271	0·029754	1·666	0·003549	0·023804
1·750	0·002385	0·032446	1·750	0·003728	0·025957
1·833	0·002498	0·035205	1·833	0·003904	0·028164
1·916	0·002612	0·038064	1·916	0·004082	0·030454
2·000	0·002726	0 041071	2·000	0·004261	0·032857
2·083	0·002839	0·044135	2·083	0·004438	0·035308
2·166	0·002952	0·047304	2·166	0·004615	0·037843
2·250	0·003067	0·050608	2·250	0·004794	0·040486
2·333	0·003180	0·053974	2·333	0·004970	0·043179
2·416	0·003293	0·057436	2·416	0·005147	0·045948
2·500	0·003407	0·061047	2·500	0·005326	0·048837
2·583	0·003521	0·064708	2·583	0·005503	0·051767
2·666	0·003634	0·068466	2·666	0·005680	0·054773
2·750	0·003748	0·072372	2·750	0·005859	0·057898
2·833	0·003861	0·076327	2·833	0·006035	0·061061
2·916	0·003975	0·080379	2·916	0·006213	0·064303
3·000	0·004089	0·084584	3·000	0·006392	0·067667

TABLE III.—*continued.*

Diameter, 0·750 in. Area, 0·4417 in.			Diameter, 0·875 in. Area, 0·6013 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·003067	0·008153	1·000	0·004176	0·006989
1·083	0·003322	0·009358	1·083	0·004522	0·008020
1·166	0·003576	0·010634	1·166	0·004868	0·009115
1·250	0·003834	0·012003	1·250	0·005219	0·010287
1·333	0·004088	0·013424	1·333	0·005566	0·011504
1·416	0·004343	0·014917	1·416	0·005912	0·012784
1·500	0·004601	0·016500	1·500	0·006263	0·014140
1·583	0·004855	0·018134	1·583	0·006610	0·015541
1·666	0·005110	0·019836	1·666	0·006957	0·017000
1·750	0·005367	0·021631	1·750	0·007307	0·018537
1·833	0·005622	0·023470	1·833	0·007654	0·020114
1·916	0·005877	0·025378	1·916	0·008000	0·021750
2·000	0·006134	0·027381	2·000	0·008351	0·023465
2·083	0·006389	0·029422	2·083	0·008698	0·025215
2·166	0·006644	0·031536	2·166	0·009044	0·027030
2·250	0·006901	0·033738	2·250	0·009395	0·028914
2·333	0·007155	0·035982	2·333	0·009742	0·030837
2·416	0·007411	0·038290	2·416	0·010088	0·032815
2·500	0·007668	0·040698	2·500	0·010439	0·034878
2·583	0·007923	0·043139	2·583	0·010786	0·036975
2·666	0·008177	0·045644	2·666	0·011132	0·039117
2·750	0·008435	0·048248	2·750	0·011483	0·041350
2·833	0·008690	0·050884	2·833	0·011830	0·043608
2·916	0·008944	0·053586	2·916	0·012176	0·045923
3·000	0·009202	0·056389	3·000	0·012527	0·048325

TABLE III.—*continued.*

Diameter, 1·000 in. Area, ·7854 in.			Diameter, 1·250 in. Area, 1·2271 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·005454	0·006115	1·000	0·008522	0·004892
1·083	0·005907	0·007019	1·083	0·009228	0·005615
1·166	0·006359	0·007976	1·166	0·009936	0·006381
1·250	0·006817	0·009002	1·250	0·010652	0·007202
1·333	0·007270	0·010068	1·333	0·011359	0·008054
1·416	0·007723	0·011188	1·416	0·012066	0·008950
1·500	0·008181	0·012375	1·500	0·012782	0·009900
1·583	0·008634	0·013600	1·583	0·013489	0·010880
1·666	0·009086	0·014877	1·666	0·014197	0·011902
1·750	0·009544	0·016223	1·750	0·014913	0·012978
1·833	0·009997	0·017603	1·833	0·015620	0·014082
1·916	0·010450	0·019032	1·916	0·016327	0·015227
2·000	0·010908	0·020535	2·000	0·017043	0·016428
2·083	0·011361	0·022067	2·083	0 017750	0·017654
2·166	0·011813	0·023652	2·166	0·018458	0·018921
2·250	0·012272	0·025304	2·250	0·019173	0·020243
2·333	0·012724	0·026987	2·333	0·019881	0·021589
2·416	0·013177	0·028718	2·416	0·020588	0·022974
2·500	0·013635	0·030523	2·500	0·021304	0·024419
2·583	0·014088	0·032354	2·583	0·022011	0·025883
2·666	0·014540	0·034233	2·666	0 022719	0·027386
2·750	0·014999	0 036186	2·750	0·023434	0·028949
2·833	0·015451	0·038163	2·833	0·024142	0 030531
2·916	0·015904	0·040189	2·916	0·024849	0·032152
3·000	0·016362	0 042292	3·000	0·025565	0·033833

TABLE III.—*continued.*

Diameter, 1·500 in. Area, 1·7671 in.			Diameter, 1·750 in. Area, 2·4052 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·012271	0·004077	1·000	0·016703	0·003494
1·083	0·013290	0·004679	1·083	0·018089	0·004010
1·166	0·014309	0·005317	1·166	0·019475	0·004557
1·250	0·015339	0·006002	1·250	0·020878	0·005144
1·333	0·016358	0·006712	1·333	0·022265	0·005752
1·416	0·017376	0·007458	1·416	0·023651	0·006392
1·500	0·018407	0·008250	1·500	0·025054	0·007070
1·583	0·019426	0·009067	1·583	0·026440	0·007770
1·666	0·020444	0·009918	1·666	0·027827	0·008500
1·750	0·021475	0·010815	1·750	0·029230	0·009269
1·833	0·022494	0·011735	1·833	0·030616	0·010057
1·916	0·023512	0·012689	1·916	0·032003	0·010875
2·000	0·024543	0·013690	2·000	0·033406	0·011733
2·083	0·025562	0·014711	2·083	0·034792	0·012608
2·166	0·026580	0·015768	2·166	0·036178	0·013515
2·250	0·027610	0·016869	2·250	0·037581	0·014457
2·333	0·028629	0·017991	2·333	0·038968	0·015418
2·416	0·029648	0·019145	2·416	0·040354	0·016407
2 500	0·030679	0·020349	2·500	0·041757	0·017439
2·583	0·031697	0·021569	2·583	0·043143	0·018487
2·666	0·032716	0·022822	2·666	0·044530	0·019558
2·750	0·033746	0·024124	2·750	0·045933	0·020675
2·833	0·034765	0·025442	2·833	0·047319	0·021804
2·916	0·035783	0·026793	2·916	0·048705	0·022962
3·000	0·036814	0·028194	3·000	0·050108	0·024163

TABLE III.—*continued.*

Diameter, 2·000 in. Area, 3·1416 in.			Diameter, 2·500 in. Area, 4·9087 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·021817	0·003057	1·000	0 034088	0·002446
1·083	0·023627	0·003509	1·083	0·036917	0·002807
1·166	0·025438	0·003988	1·166	0·039747	0·003190
1·250	0·027271	0·004501	1·250	0·042610	0·003601
1·333	0·029081	0·005034	1·333	0·045439	0·004027
1·416	0·030892	0·005594	1·416	0·048269	0·004475
1·500	0·032725	0·006188	1·500	0·051132	0·004950
1·583	0·034536	0·006800	1·583	0·053962	0·005440
1·666	0·036347	0·007438	1·666	0·056791	0·005951
1·750	0·038179	0·008111	1·750	0·059654	0·006489
1·833	0·039990	0·008801	1·833	0·062484	0·007041
1·916	0·041800	0·009517	1·916	0·065313	0·007613
2·000	0·043634	0·010268	2·000	0·068176	0·008214
2·083	0·045444	0·011034	2·083	0·071006	0·008827
2·166	0·047255	0·011826	2·166	0·073835	0·009460
2·250	0·049087	0 012652	2·250	0·076698	0·010121
2·333	0·050898	0·013493	2·333	0·079528	0·010795
2·416	0·052709	0·014359	2·416	0·082357	0·011487
2·500	0·054542	0·015262	2·500	0·085220	0·012209
2·583	0·056352	0·016177	2·583	0·088050	0·012941
2·666	0·058163	0·017116	2·666	0·090879	0·013693
2·750	0·059996	0·018093	2·750	0·093742	0·014475
2·833	0·061807	0·019082	2·833	0·096572	0·015265
2·916	0·063617	0·020095	2·916	0·099401	0·016076
3·000	0·065450	0·021146	3·000	0·102264	0·016916

TABLE III.—*continued.*

Diameter, 3·000 in. Area, 7·0686 in.			Diameter, 3·5000 in. Area, 9·6211 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·049087	0·002038	1·000	0·066813	0·001747
1·083	0·053162	0·002339	1·083	0·072359	0·002005
1·166	0·057236	0·002658	1·166	0·077904	0·002279
1·250	0·061359	0·003001	1·250	0·083516	0·002572
1·333	0·065433	0·003356	1·333	0 089062	0·002876
1·416	0·069508	0·003729	1·416	0·094607	0·003196
1·500	0·073631	0·004125	1·500	0·100220	0·003535
1·583	0·077705	0·004533	1·583	0·105765	0·003885
1·666	0·081780	0·004959	1·666	0·111311	0·004250
1·750	0·085903	0·005408	1·750	0·116923	0 004634
1·833	0·089977	0·005867	1·833	0·122468	0 005028
1·916	0·094052	0·006344	1·916	0·128014	0·005437
2·000	0·098175	0·006845	2·000	0·133626	0·005866
2·083	0·102249	0·007356	2·083	0·139172	0·006304
2·166	0·106323	0·007884	2·166	0·144717	0·006757
2·250	0·110447	0·008435	2·250	0·150330	0·007228
2·333	0·114521	0·008996	2·333	0 155875	0·007709
2·416	0·118595	0·009572	2·416	0·161420	0·008204
2·500	0·122719	0·010174	2·500	0·167033	0·008719
2·583	0·126793	0·010784	2·583	0·172578	0·009243
2·666	0·130867	0·011411	2·666	0·178124	0·009779
2·750	0·134990	0·012062	2·750	0·183736	0·010337
2·833	0·139065	0 012721	2·833	0·189282	0·010902
2·916	0·143139	0·013396	2·916	0·194827	0·011481
3·000	0·147262	0·014097	3·000	0·200439	0·012081

TABLE III.—*continued*.

Diameter, 4·000 in. Area, 12·566 in.			Diameter, 4·500 in. Area, 15·904 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·087264	0·001529	1·000	0·110444	0 001358
1·083	0·094507	0·001755	1·083	0·119611	0·001559
1·166	0·101750	0·001994	1·166	0·128778	0·001772
1·250	0·109080	0·002250	1·250	0·138055	0·002000
1·333	0·116323	0·002517	1·333	0·147222	0·002235
1·416	0·123566	0·002797	1·416	0·156390	0·002485
1·500	0·130896	0·003094	1·500	0·165667	0·002747
1·583	0·138139	0·003400	1·583	0·174834	0·003019
1·666	0·145382	0·003719	1·666	0·184000	0·003305
1·750	0·152712	0·004056	1·750	0·193278	0·003600
1·833	0·159954	0·004401	1·833	0·202445	0·003908
1·916	0·167198	0·004758	1·916	0·211611	0·004228
2·000	0·174528	0·005134	2·000	0·220889	0·004559
2·083	0·181770	0·005517	2·083	0·230056	0·004899
2·166	0·189014	0·005913	2·166	0·239222	0·005250
2·250	0·196344	0·006326	2·250	0·248500	0·005617
2·333	0·203587	0·006747	2·333	0·257667	0·005991
2·416	0·210830	0·007179	2·416	0·266834	0·006375
2·500	0·218160	0·007631	2·500	0·276111	0·006776
2·583	0·225403	0·008088	2·583	0·285278	0·007182
2·666	0·232646	0·008558	2·666	0·294444	0·007600
2·750	0·239976	0·009047	2·750	0·303722	0·008039
2·833	0·247218	0·009541	2·833	0·312889	0·008477
2·916	0·254461	0·010047	2·916	0·322056	0·008928
3·000	0·261792	0·010573	3·000	0·331333	0·009394

TABLE III.—*continued.*

Diameter, 5·000 in. Area, 19·635 in.			Diameter, 6·000 in. Area, 28·274 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·136354	0·001223	1·000	0·196347	0·001019
1·083	0·147671	0·001404	1·083	0·212644	0·001169
1·166	0·158989	0·001595	1·166	0·228941	0·001329
1·250	0·170443	0·001800	1·250	0·245434	0·001500
1·333	0·181760	0·002014	1·333	0·261731	0·001678
1·416	0·193077	0·002237	1·416	0·278028	0·001865
1·500	0·204531	0·002475	1·500	0·294521	0·002062
1·583	0·215848	0·002720	1·583	0·310818	0·002267
1·666	0·227166	0·002975	1·666	0·327114	0·002479
1·750	0·238620	0·003244	1·750	0·343608	0·002703
1·833	0·249937	0·003520	1·833	0·359904	0·002934
1·916	0·261254	0·003807	1·916	0·376201	0·003172
2·000	0·272708	0·004107	2·000	0·392694	0·003422
2·083	0·284025	0·004413	2·083	0·408991	0·003678
2·166	0·295343	0·004730	2·166	0·425288	0·003942
2·250	0·306797	0·005061	2·250	0·441781	0·004217
2·333	0·318114	0·005397	2·333	0·458078	0·004498
2·416	0·329432	0·005743	2·416	0·474375	0·004786
2·500	0·340885	0·006105	2·500	0·490868	0·005087
2·583	0·352203	0·006471	2·583	0·507165	0·005392
2·666	0·363520	0·006846	2·666	0·523462	0·005705
2·750	0·374974	0·007237	2·750	0·539955	0·006031
2·833	0·386291	0·007633	2·833	0·556251	0·006360
2·916	0·397609	0·008038	2·916	0·572548	0·006698
3·000	0·409062	0·008458	3·000	0·589041	0·007048

TABLE III.—*continued.*

Diameter, 7·000 in. Area, 38·484 in.			Diameter, 8·000 in. Area, 50·265 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·267250	0·000873	1·000	0·349062	0·000764
1·083	0·289432	0·001002	1·083	0·378035	0·000877
1·166	0·311613	0·001139	1·166	0·407007	0·000997
1·250	0·334062	0·001286	1·250	0·436328	0·001125
1·333	0·356244	0·001438	1·333	0·465300	0·001258
1·416	0·378426	0·001598	1·416	0·494272	0·001398
1·500	0·400875	0·001767	1·500	0·523594	0·001547
1·583	0·423057	0·001942	1·583	0·552566	0·001700
1·666	0·445238	0·002125	1·666	0·581538	0·001859
1·750	0·467687	0·002317	1·750	0·610859	0·002028
1·833	0·489869	0·002514	1·833	0·639831	0·002200
1·916	0·512051	0·002719	1·916	0·668804	0·002379
2·000	0·534500	0·002933	2·000	0·698125	0·002567
2·083	0·556682	0·003152	2·083	0·727097	0·002758
2·166	0·578863	0·003378	2·166	0·756069	0·002956
2·250	0·601312	0·003614	2·250	0·785390	0·003163
2·333	0·623494	0·003855	2·333	0·814363	0 003373
2·416	0·645676	0·004102	2·416	0·843335	0·003589
2·500	0·668125	0·004360	2·500	0·872656	0·003815
2·583	0·690307	0·004621	2·583	0·901628	0·004044
2·666	0·712488	0·004889	2·666	0·930600	0·004279
2·750	0·734937	0·005169	2·750	0·959921	0·004523
2·833	0·757119	0·005451	2·833	0·988894	0·004770
2·916	0·779301	0·005740	2·916	1·017866	0·005024
3·000	0·801750	0·006041	3·000	1·047187	0·005286

TABLE III.—*continued.*

Diameter, 9·000 in. Area, 63·617 in.			Diameter, 10·000 in. Area, 78·540 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·441785	0·000679	1·000	0·545417	0·000611
1·083	0·478453	0·000779	1·083	0·590686	0·000702
1·166	0·515121	0·000886	1·166	0·635956	0·000797
1·250	0·552231	0·001000	1·250	0·681771	0·000900
1·333	0·588899	0·001117	1·333	0·727040	0·001007
1·416	0·625567	0·001242	1·416	0·772310	0·001119
1·500	0·662677	0·001374	1·500	0·818125	0·001237
1·583	0·699345	0·001509	1·583	0·863394	0·001360
1·666	0·736013	0·001651	1·666	0·908664	0·001488
1·750	0·773123	0·001800	1·750	0·954479	0·001622
1·833	0·809791	0·001954	1·833	0·999749	0·001760
1·916	0·846459	0·002114	1·916	1·045018	0·001903
2·000	0·883570	0·002279	2·000	1·090834	0·002053
2·083	0·920237	0·002449	2·083	1·136103	0·002207
2·166	0·956906	0·002625	2·166	1·181372	0·002365
2·250	0·994016	0·002809	2·250	1·227187	0·002530
2·333	1·030684	0·002995	2·333	1·272457	0·002698
2·416	1·067352	0·003187	2·416	1·317727	0·002872
2·500	1·104462	0·003388	2·500	1·363542	0·003052
2·583	1·141130	0·003591	2·583	1·408811	0·003235
2·666	1·177798	0·003800	2·666	1·454081	0·003423
2·750	1·214908	0·004019	2·750	1·499896	0·003619
2·833	1·251576	0·004238	2·833	1·545165	0·003816
2·916	1·288244	0·004464	2·916	1·590435	0·004019
3·000	1·325354	0·004697	3·000	1·636250	0·004229

TABLE III.—*continued.*

Diameter, 11·000 in. Area, 95·033 in.			Diameter, 12·000 in. Area, 113·097 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·659952	0·000556	1·000	0·785396	0·000509
1·083	0·714727	0·000638	1·083	0·850584	0 000585
1·166	0·769503	0·000725	1·166	0 915771	0·000664
1·250	0·824940	0·000818	1·250	0·981745	0·000750
1·333	0·879715	0·000915	1·333	1·046933	0 000839
1·416	0·934491	0·001017	1·416	1·112120	0·000932
1·500	0·989927	0·001125	1·500	1·178094	0·001031
1·583	1·044703	0·001236	1·583	1·243282	0·001133
1·666	1·099479	0·001352	1·666	1·308469	0·001239
1·750	1·154915	0·001475	1·750	1·374443	0·001352
1·833	1·209691	0 001600	1·833	1·439630	0·001467
1·916	1·264467	0·001730	1·916	1·504818	0 001586
2·000	1·319903	0·001867	2·000	1·570792	0·001711
2·083	1·374679	0·002006	2·083	1·635979	0·001839
2·166	1·429455	0·002150	2·166	1·701167	0·001971
2·250	1·484892	0·002300	2·250	1·767140	0·002108
2·333	1·539667	0·002453	2·333	1·832328	0·002249
2·416	1·594442	0·002611	2·416	1·897516	0·002393
2·500	1·649878	0·002775	2·500	1·963490	0·002543
2·583	1·704654	0·002941	2·583	2·028677	0·002696
2·666	1·759430	0·003112	2·666	2·093865	0·002853
2·750	1·814866	0·003290	2·750	2·159838	0·003015
2·833	1·869642	0·003470	2·833	2·225026	0·003180
2·916	1·924418	0·003654	2·916	2·290214	0·003349
3·000	1·979854	0·003845	3·000	2·356187	0·003524

TABLE III.—*continued.*

Diameter, 13·000 in. Area, 132·732 in.			Diameter, 14·000 in. Area, 153·938 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	0·921750	0·000470	1·000	1·069014	0·000437
1·083	0·998255	0·000540	1·083	1·157742	0·000501
1·166	1·074760	0·000613	1·166	1·246470	0·000570
1·250	1·152187	0·000692	1·250	1·336267	0·000643
1·333	1·228693	0·000774	1·333	1·424995	0·000719
1·416	1·305198	0·000860	1·416	1·513724	0·000799
1·500	1·382625	0·000952	1·500	1·603521	0·000884
1·583	1·459130	0·001046	1·583	1·692249	0·000970
1·666	1·535635	0·001144	1·666	1·780977	0·001062
1·750	1·613062	0·001248	1·750	1·870774	0·001158
1·833	1·689568	0·001354	1·833	1·959502	0·001257
1·916	1·766073	0·001464	1·916	2·048230	0·001359
2·000	1·843500	0·001579	2·000	2·138028	0·001466
2·083	1·920005	0·001697	2·083	2·226756	0·001576
2·166	1·996510	0·001819	2·166	2·315484	0·001689
2·250	2·073937	0·001946	2·250	2·405281	0·001807
2·333	2·150443	0·002076	2·333	2·494009	0·001927
2·416	2·226948	0·002209	2·416	2·582737	0·002051
2·500	2·304374	0·002348	2·500	2·672535	0·002180
2·583	2·380880	0·002488	2·583	2·761263	0·002310
2·666	2·457385	0·002633	2·666	2·849991	0·002445
2·750	2·534812	0·002783	2·750	2·939788	0·002584
2·833	2·611318	0·002935	2·833	3·028516	0·002725
2·916	2·687823	0·003091	2·916	3·177244	0·002870
3·000	2·765250	0·003253	3·000	3·207042	0·003020

TABLE III.—*continued.*

Diameter, 15·000 in. Area, 176·715 in.			Diameter, 16·000 in. Area, 201·062 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	1·227187	0·000407	1·000	1·396264	0·000382
1·083	1·329044	0·000468	1·083	1·512154	0·000439
1·166	1·430901	0·000532	1·166	1·628044	0·000498
1·250	1·533984	0·000600	1·250	1·745330	0·000562
1·333	1·635841	0·000671	1·333	1·861220	0·000629
1·416	1·737697	0·000746	1·416	1·977108	0·000699
1·500	1·840781	0·000825	1·500	2·094396	0·000773
1·583	1·942638	0·000907	1·583	2·210286	0·000850
1·666	2·044494	0·000992	1·666	2·326176	0·000930
1·750	2·147578	0·001081	1·750	2·443462	0·001013
1·833	2·249435	0·001173	1·833	2·559352	0·001100
1·916	2·351291	0·001269	1·916	2·675242	0·001189
2·000	2·454375	0·001369	2·000	2·792528	0·001283
2·083	2·556231	0·001471	2·083	2·908418	0·001379
2·166	2·658088	0·001577	2·166	3·024308	0·001478
2·250	2·761172	0·001687	2·250	3·141594	0·001581
2·333	2·863028	0·001799	2·333	3·257484	0·001687
2·416	2·964885	0·001914	2·416	3·373373	0·001795
2·500	3·067968	0·002035	2·500	3·490660	0·001908
2·583	3·169825	0·002157	2·583	3·606550	0·002022
2·666	3·271682	0·002282	2·666	3·722440	0·002139
2·750	3·374765	0·002412	2·750	3·839725	0·002261
2·833	3·476622	0·002544	2·833	3·955615	0·002385
2·916	3·578479	0·002679	2·916	4·071505	0·002512
3·000	3·681562	0·002819	3·000	4·188792	0·002643

TABLE III.—*continued.*

Diameter, 17·000 in. Area, 226·980 in.			Diameter, 18·000 in. Area, 254·469 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	1·576250	0·000359	1·000	1·767146	0·000339
1·083	1·707079	0·000413	1·083	1·913819	0·000397
1·166	1·837907	0·000469	1·166	2·060492	0·000443
1·250	1·970312	0·000529	1·250	2·208932	0·000500
1·333	2·101141	0·000592	1·333	2·355605	0·000559
1·416	2·231970	0·000658	1·416	2·502278	0·000621
1·500	2·364375	0·000728	1·500	2·650719	0·000687
1·583	2·495204	0·000800	1·583	2·797392	0·000755
1·666	2·626032	0·000875	1·666	2·944065	0·000825
1·750	2·758437	0·000954	1·750	3·092505	0·000900
1·833	2·889266	0·001035	1·833	3·239178	0·000976
1·916	3·020095	0·001120	1·916	3·385852	0·001056
2·000	3·152500	0·001208	2·000	3·534292	0·001140
2·083	3·283329	0·001298	2·083	3·680965	0·001225
2·166	3·414157	0·001391	2·166	3·827638	0·001312
2·250	3·546562	0·001489	2·250	3·976078	0·001404
2·333	3·677391	0·001588	2·333	4·122751	0·001498
2·416	3·808220	0·001689	2·416	4·269424	0·001594
2·500	3·940625	0·001796	2·500	4·417864	0·001694
2·583	4·071454	0·001903	2·583	4·564538	0·001795
2·666	4·202282	0·002014	2·666	4·711210	0·001900
2·750	4·334687	0·002129	2·750	4·859651	0·002009
2·833	4·465516	0·002245	2·833	5·006324	0·002119
2·916	4·596345	0·002364	2·916	5·152997	0·002232
3·000	4·728750	0·002488	3·000	5·301437	0·002348

TABLE III.—*continued.*

Diameter, 21·000 in. Area, 346·361 in.			Diameter, 24·000 in. Area, 452·390 in.		
Velocity per second.	Quantity.	Loss of head per foot.	Velocity per second.	Quantity.	Loss of head per foot.
1·000	2·405285	0·000291	1·000	3·141597	0·000254
1·083	2·604923	0·000334	1·083	3·402350	0·000292
1·166	2·804562	0·000379	1·166	3·663102	0·000332
1·250	3·006606	0·000428	1·250	3·926996	0·000375
1·333	3·206244	0·000479	1·333	4·187749	0·000419
1·416	3·405883	0·000532	1·416	4·448502	0·000466
1·500	3·607927	0·000589	1·500	4·712396	0·000516
1·583	3·807566	0·000647	1·583	4·973148	0·000567
1·666	4·007204	0·000703	1·666	5·233901	0·000620
1·750	4·209248	0·000772	1·750	5·497795	0·000676
1·833	4·408887	0·000837	1·833	5·758548	0·000733
1·916	4·608525	0·000906	1·916	6·019300	0·000793
2·000	4·810569	0·000977	2·000	6·283194	0·000855
2·083	5·010208	0·001050	2·083	6·543947	0 000919
2·166	5·209847	0·001155	2·166	6·804699	0·000985
2·250	5·411891	0·001204	2·250	7·068594	0·001054
2·333	5·611529	0·001284	2·333	7·329346	0·001124
2·416	5·811168	0·001366	2·416	7·590099	0·001196
2·500	6·013212	0·001452	2·500	7·853993	0·001272
2·583	6·212850	0·001539	2·583	8·114745	0·001348
2·666	6·412488	0 001629	2·666	8 375498	0·001426
2·750	6·614533	0·001722	2·750	8·639392	0·001508
2·833	6·814172	0·001816	2·833	8·900145	0·001590
2·916	7·013810	0·001912	2·916	9·160897	0·001674
3·000	7·215854	0·002112	3·000	9·424792	0·001762

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Ditto, drawn and engraved to half-size: fig. 1, old valve, $\frac{1}{16}$-inch lap; fig. 2, $\frac{3}{8}$-inch lap; fig. 3, $\frac{3}{4}$-inch lap; fig. 4, $\frac{7}{8}$-inch lap, Gray's patent; fig. 5, 1-inch lap.

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